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ADVANCED MAINTENANCE FREE AIRCRAFT BATTERY SYSTEM (AMFABS)

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13. ABSTRACT *(Maximum 200 Words)*
Vented nickel cadmium (NiCd) batteries are used in most main aircraft battery applications. To keep the batteries fully charged and at their rated capacity, they require a topping charge or overcharge. This overcharge process results in conversion of water into gaseous oxygen and hydrogen. Over several charge and discharge cycles, these gasses escape from the cell vent caps, resulting in water usage and forcing a maintenance action to keep the battery in a healthy state. This maintenance, which requires special facilities and training, drives up the life cycle costs of vented battery systems. Over the past few years, there have been several initiatives to reduce the operating costs of aircraft batteries. In particular, the United States Air Force (USAF) is involved in the development of maintenance free battery systems. There are two general approaches to reduce the maintenance cost of batteries. One approach is to develop a disposable battery system, such that after some interval the battery is simply replaced. The other approach is to develop a battery system that will function properly without maintenance for an extended period. The subject of this report is a system that does not require any scheduled maintenance for the design life of the aircraft. This approach is currently used in spacecraft applications where battery maintenance is not practical.

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1 INTRODUCTION

1.1 The Rationale for a Maintenance Free Aircraft Battery System

Main aircraft batteries are used for emergency backup of essential equipment, hold-up for flight critical equipment, auxiliary DC power for maintenance activities, and starting power for auxiliary power units and engines.

Vented Nickel Cadmium (NiCd) batteries are used in most main aircraft battery applications. To keep the batteries fully charged and at their rated capacity, they require a topping charge or overcharge. This overcharge process results in conversion of water into gaseous oxygen and hydrogen. Over several charge and discharge cycles these gasses escape from the cell vent caps resulting in water usage, thus forcing a maintenance action to keep the battery in a healthy state. This maintenance, which requires special facilities and training, drives up the life cycle costs of vented battery systems. Over the past few years, there have been several initiatives to reduce the operating costs of aircraft batteries. In particular, the United States Air Force (USAF) is involved in the development of maintenance free battery systems.

There are two general approaches to reduce the maintenance cost of batteries. One approach is to develop a disposable battery system, such that after some time interval the battery is simply replaced. The other approach is to develop a battery system that will function properly without maintenance for an extended period. The subject of this paper is a system that does not require any scheduled maintenance for the design life of the aircraft. This approach is currently used in spacecraft applications where battery maintenance is not practical.

1.2 Advanced Maintenance Free Aircraft Battery System (AMFABS) Contract

In June of 1991 the USAF, through Wright Laboratory, awarded contract F33615-91-C-2108 to develop a 20 year / 20,000 flight hour Advanced Maintenance Free Aircraft Battery System (AMFABS). The AMFABS team is identified in Table 1-1.

Table 1-1. AMFABS Team

Team Member	Role
Sponsor • Wright Laboratory, Wright Patterson AFB, Ohio	• Program Management • Requirements Definition
Principals • ELDEC Corporation, Bothell, Washington	• Prime Contractor • System Integration • Design, Build, and Test: Battery Charger Analyzer Unit Battery Electronics Assembly
• Eagle-Picher Industries, Colorado Springs, Colorado	• Battery Design, Build, and Test
Subcontractor • Battelle Institute, Columbus, Ohio	• System Requirements Definition

AMFABS must be adaptable to all USAF aircraft, which include applications from 1 to 100Ah. It needs to provide state-of-health information to insure proper operation and inform the flight and ground crews of the state-of-charge of the battery. Finally, the system must have charge/discharge characteristics, size, and weight comparable to vented NiCd technology.

2 PROJECT OVERVIEW

2.1 Requirements Definition

We performed several studies and analyses to define the requirements for the AMFABS design. An analysis of military battery specifications -- MIL-B-8565J, 26026B, 26220D, 49450, 81757C, and 83424 -- resulted in a matrix that summarizes all of the pertinent specification items *(1)*. In addition, we generated a database of all USAF aircraft to identify the current and proposed battery and charger characteristics, main battery functions, and estimated inventory *(2)*.

Technical trade studies resulted in specific design requirements for the AMFABS system. These trade studies are summarized in Table 2-1.

Table 2-1. Technical Trade Studies

Study	Results
Modularity: Determine the best packaging approach to meet the adaptability requirements.	**Family of cell sizes. Family of converter sizes. Independently removable modules.** A modular design is easily adapted to different applications and results in improved testability and maintainability. It increases the size and cost by 15-20% compared to a full custom approach.
Hardware/Software: Determine the best approach for providing adaptable charge control and state-of-health functions.	**Motorola 68332 uC and ADA** A microcontroller-based design provides the greatest flexibility and capability in the smallest size.
Converter Topology: Identify the best circuit topology for the converter.	**10A flyback converters for low power. 30-50A full bridge converters for high power.** Two converter topologies minimize the size increase due to the modular packaging approach.
Cooling: Identify the best cooling approach to fit the majority of potential installations	**Passively cooled design** Requires least specialized aircraft interface, but results in largest size for BCAU. Forced air cooling could be 30% smaller; conduction cooled could be 40% smaller.
Environment: Identify a "super set" of environmental requirements to cover the majority of potential installations.	**All modules designed to withstand most severe environments** MIL-STD-810E, 20Grms random vibration MIL-E-5400T, Class 2 (71 °C / 70,000 ft.)

The technical trade studies, in conjunction with the military specification matrix and USAF database, formed the basis for the AMFABS general specification BC2000B *(3)*. The BC2000B can be tailored by slash sheets to define particular aircraft installation requirements. We generated the BC2000/01 *(4)* to define this program's deliverable configuration, which is based on the battery system and environmental requirements of the E-8 aircraft. Documents BC2000B and BC2000/01 are included as Appendices A and B, respectively.

2.2 System Design

The final AMFABS design is a sealed NiCd battery and a modular, microcontroller-based, Battery Charger Analyzer Unit (BCAU). A block diagram of the system is illustrated in Figure 2-1.

We selected a sealed NiCd battery based on the long life performance proven in spacecraft battery designs. Transitioning spacecraft battery technology to the aircraft application was then the primary battery challenge. The BCAU challenge was to design a modular, passively cooled unit that is rugged, compact, and lightweight.

Perhaps the most critical system consideration for AMFABS was to develop a charging algorithm that would keep the battery fully charged without degrading its cycle life. We characterized the battery cells at different charge rates and temperatures to determine the optimum charging rate. Data from this testing are presented in the *Battery Test Results* section.

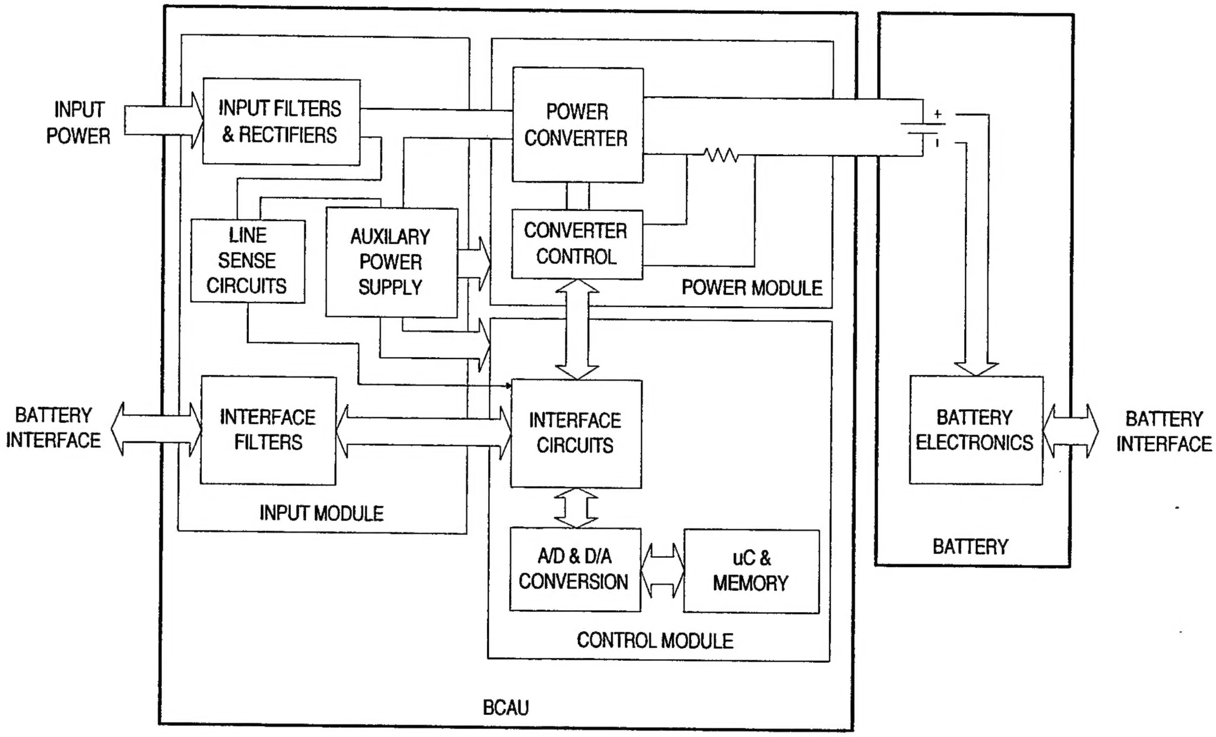

Figure 2-1. AMFABS Block Diagram

2.3 Battery Design

The battery, illustrated in Figure 2-2, is a 24V, 20 cell, sealed NiCd rated at 42Ah end-of-life capacity. The design weighs 110 pounds and has outline dimensions and interfaces as illustrated in Figure 2-3. Its cell specific energy is 34Wh/Kg and energy density is 72Wh/L.

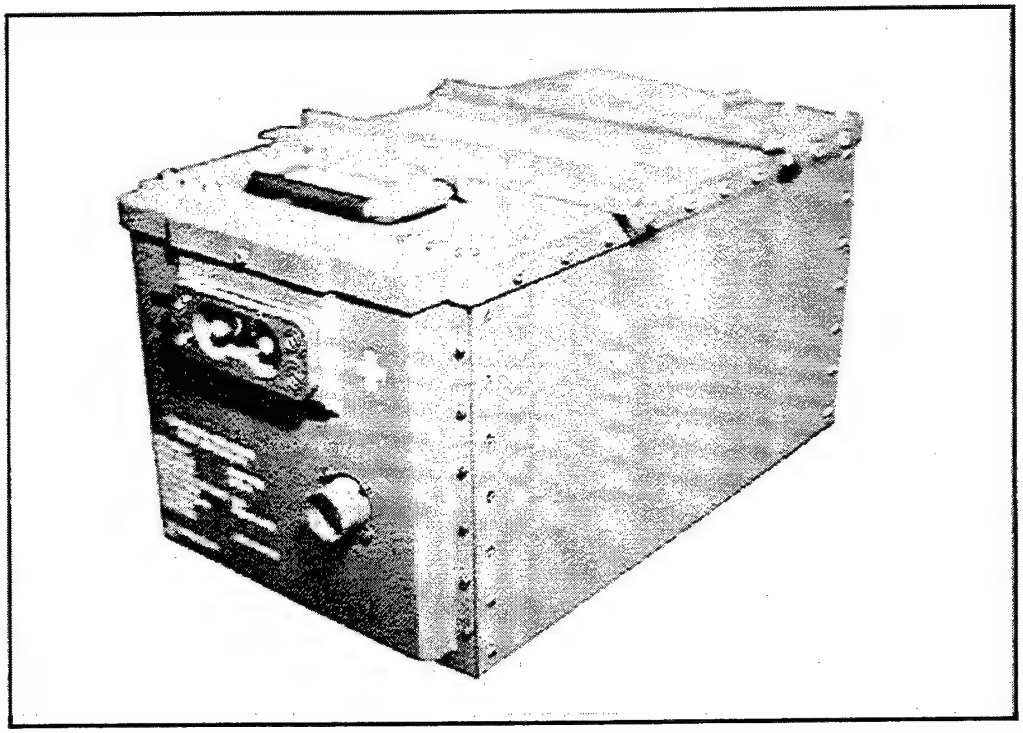

Figure 2-2. AMFABS Battery

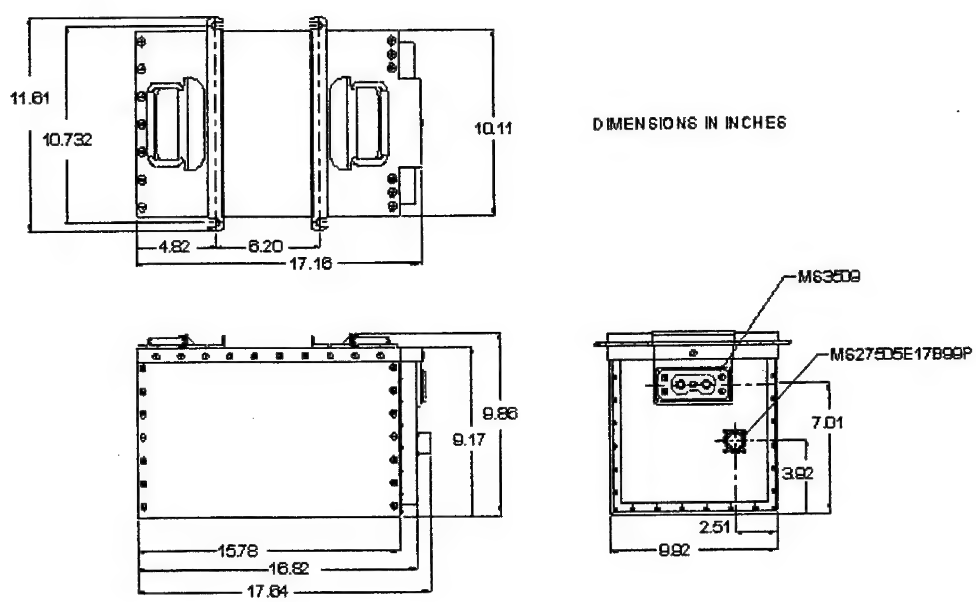

Figure 2-3. Battery Outline Dimensions & Interfaces

New developments in the battery design range from the internal cell materials to final battery packaging techniques. We developed test programs to evaluate the electrodes, electrolyte, separators, and cell cases. Performance over the full temperature range and long term life were used to determine the optimum cell design. Several cells using combinations of the most

promising cell components were built and tested for impedance, flooded capacity, and cycle life to determine the best configuration. The cell development work is summarized in Table 2-2.

Table 2-2. Cell Development Summary

Development	Results
Electrodes: Determine the best electrode design for uniform porosity, high loading levels, and high strength.	**Slurry-Sintered Substrate with Dual Impregnation Process** An improved sinter process yields better uniformity. An improved impregnation process yields high capacity and long life.
Separator: Determine the optimum separator material for the aircraft temperature range.	**Polypropylene impregnated with polybenzimadazole (PBI)** A low-to-moderate cost, long life separator was developed *(5).*
Electrolyte: Determine the best electrolyte concentration and additives for full temperature performance.	**1.30 specific gravity KOH with no additives** The standard vented NiCd electrolyte offers the best combination of performance and life.
Cell Case & Seals: Determine the best case material and seal for long term performance.	**Nylon Case / Nylon Compression Seal** Nylon cases were verified for long life applications. A new nylon compression seal was developed.

The interface between the battery and BCAU is accomplished by a Battery Electronics Assembly, consisting of transducers for voltage, current, and temperature. The transducers are designed to minimize their effect on battery performance. For example, the current transducer is an electromagnetic element that does not effect the battery impedance and allows for currents up to 2000A.

The battery packaging is illustrated in Figure 2-4. The battery cells are configured in two rows with heat sinks between the cells to minimize temperature rise and maintain a near isothermal battery. The battery container is constructed of two stiff end plates connected by a base and cover. The end plates are designed to clamp the two rows of cells, functioning similarly to load rod designs in spacecraft batteries.

The Battery Electronics Assembly is mounted integral to the front panel in an enclosure that is separate from the battery cells for environmental isolation.

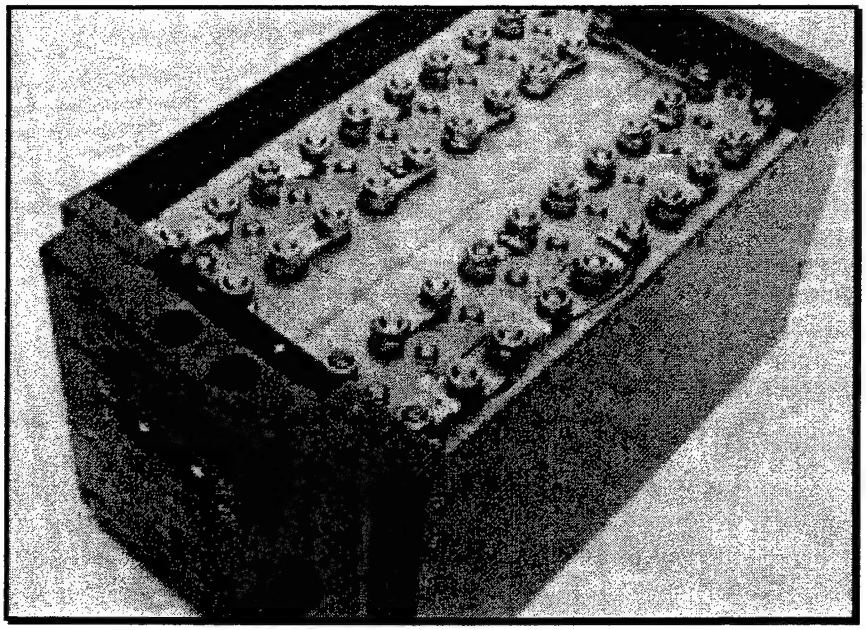

Figure 2-4. Battery Packaging

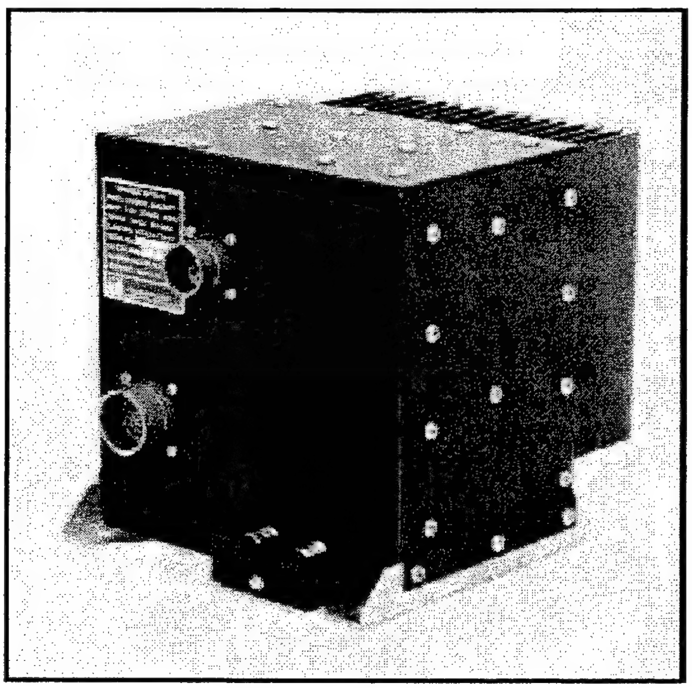

Figure 2-5. AMFABS BCAU

2.4 BCAU Design

The BCAU, illustrated in Figure 2-5, is comprised of four basic building blocks, the Input Module, Control Module, Power Module, and Base Assembly. For this program's 1200W output, it weighs 9.6 pounds and has the outline dimensions and interfaces illustrated in Figure 2-6.

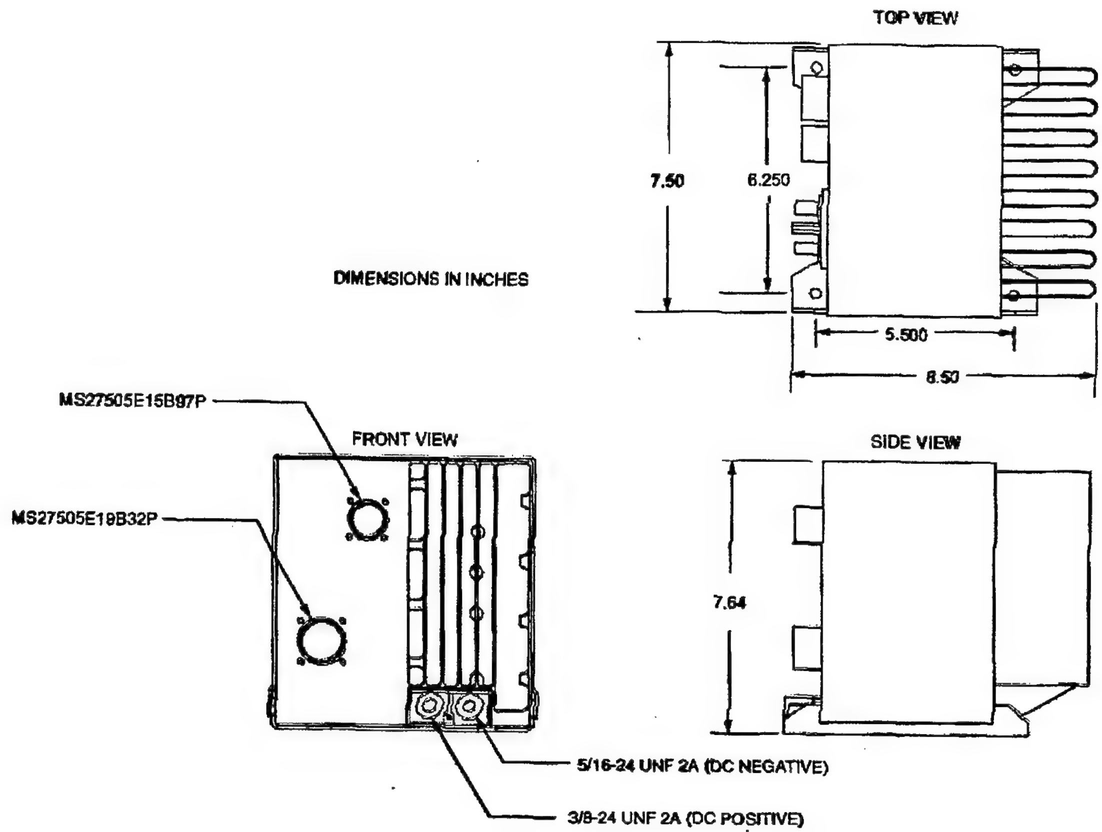

Figure 2-6. BCAU Outline Dimensions & Interfaces

The Input Module contains the EMI filters, auxiliary power supply, and input line sense circuitry. The module is designed to accept either three-phase 115Vac or 270Vdc input power. Filtering is provided for the power and interface lines. Auxiliary power is generated with a flyback power converter operating at 100 kHz. These electronics, packaged as a Filter Assembly and an Auxiliary Power Supply Circuit Card Assembly (CCA), are mounted to a stiff, lightweight frame. The frame includes integral fins for rejecting this module's 29 W, provides separate shielded enclosures for its filter and power supply elements, and serves as the BCAU's front panel with MIL-C-38999 connectors.

The Control Module provides all system control and built-in-test (BIT). It operates from an uninterruptable input voltage, thereby maintaining control with or without BCAU input power. This module contains all of the interface circuits to the battery, a Motorola 68332 microcontroller and its memory, A/D and D/A converters, and an RS232 interface. The ADA software provides BIT processing and fault detection/recording at both the Line Replaceable Unit (LRU) and Shop Replaceable Unit (SRU) levels. The software communicates to the aircraft or maintenance crew via an RS232 port. The module electronics, packaged as a single Microprocessor Controller CCA, are mounted to a lightweight frame in the center of the BCAU. This frame serves as a card stiffener, provides an efficient heat conduction path to the BCAU cover, and completes the shielding for the Input Module Filter Assembly.

The Power Module provides the primary power conversion from the Input Module to the battery. Constant voltage and constant current operating modes are provided, with protection from over current, voltage, and temperature. It is implemented with either 10A flyback or 30-50A full bridge, 500kHz high density converters. Up to three converters can be connected in parallel to

provide systems with up to 4500W output. The module electronics, packaged as Converter Control and Converter Power CCA's, are mounted to a dip-brazed finned heat sink at the rear of the BCAU. The fin spacing and thickness are optimized to maximize the heatsink performance at minimum weight. The Power Module is illustrated in Figure 2-7 with its EMI shield and Converter Control CCA removed to reveal the Converter Power CCA. This CCA, which includes the high current circuitry and 128W dissipation, uses insulated metal substrate technology to minimize the heat sink-to-junction temperature rise.

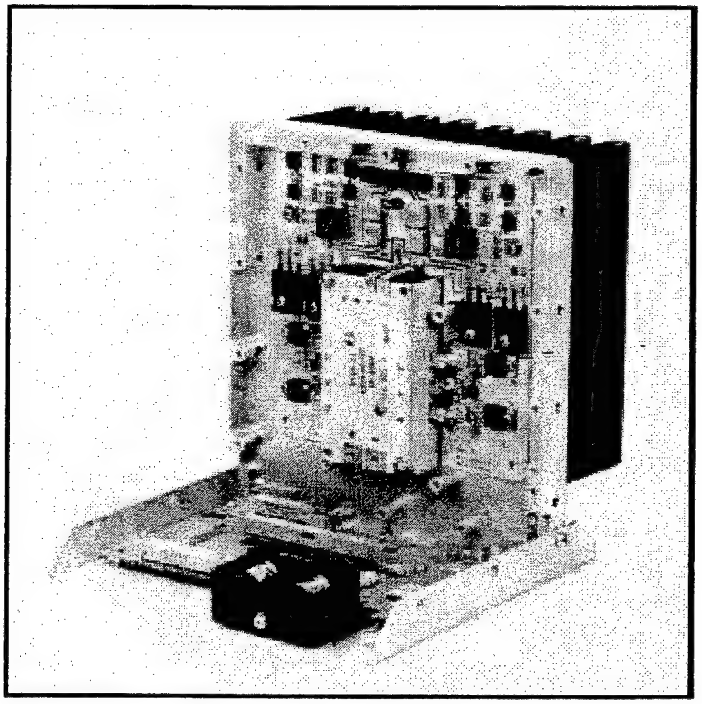

Figure 2-7. Power Module and Base Assembly

The Motherboard CCA, which is integral to the Base Assembly, is the common signal and power bus into which each module is plugged. All module interconnects are accomplished using either MIL-C-55302 type connectors or terminal blocks (for the output current path). Accordingly, no wires are used.

2.5 Battery Test Results

Comprehensive Design Verification Testing (DVT) and qualification testing were performed on both the battery and BCAU.

Battery testing included both cell characterization and battery tests. The cell characterization testing was designed to determine the optimum charging rate and performance over temperature. The test data shown in Figure 2-8 demonstrates that the base charge rate should vary with temperature to achieve the highest capacity. It also shows that constant current charging at the temperature extremes results in a reduction in capacity.

CAPACITY vs TEMPERATURE at VARIOUS RATES

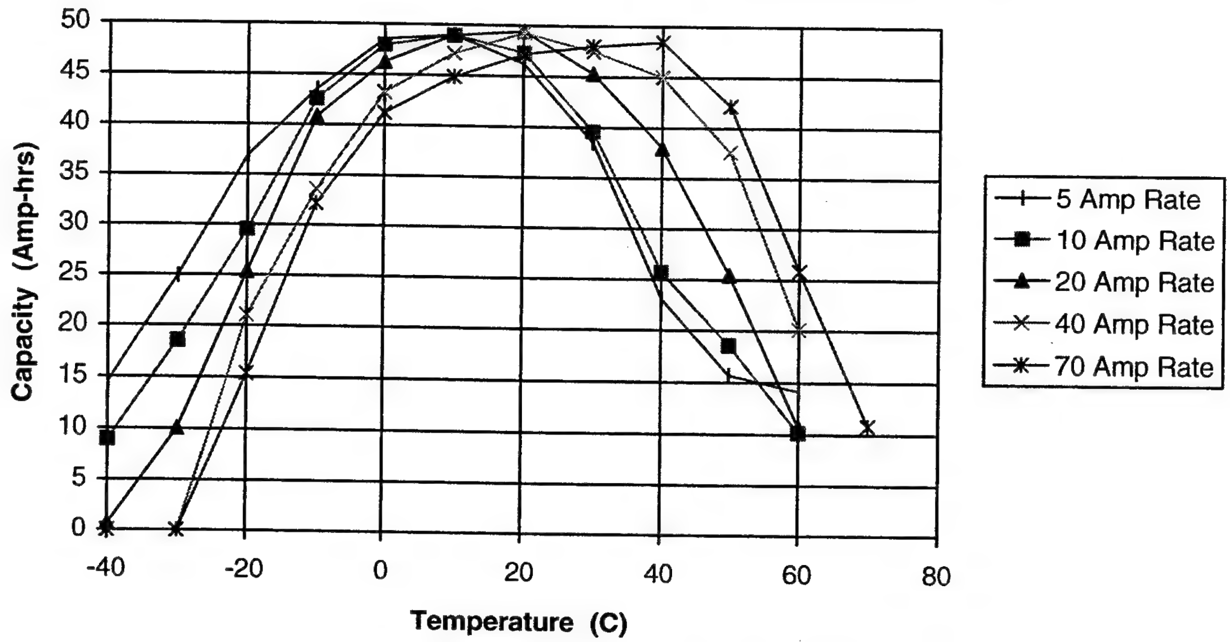

Figure 2-8. Cell Characterization Test Results

Battery DVT results for impedance, capacity, and charge time performance are summarized in Table 2-3.

Table 2-3. Battery DVT Summary

Test	Requirement			Results		
Impedance	< 10 milliOhms at 25 °C			7 milliOhms at 25 °C		
C-Rate Capacity	**Temp**	**Min. Discharge Time**		**Temp**	**Min. Discharge Time**	
	49 °C	50 minutes		49 °C	82 minutes	
	25 °C	60 minutes		25 °C	84 minutes	
	-18 °C	45 minutes		-18 °C	73 minutes	
	-40 °C	30 minutes		-40 °C	43 minutes.	
Charge Time	**Temp**	**80%**	**100%**	**Temp**	**80%**	**100%**
	49 °C	2 hrs	3 hrs	49 °C	1.0 hrs	1.3 hrs
	25 °C	1 hrs	2 hrs	25 °C	1.0 hrs	1.2 hrs
	-18 °C	3 hrs	5 hrs	-18 °C	1.5 hrs	1.8 hrs
	-40 °C	4 hrs	6 hrs	-40 °C	2.0 hrs	2.4 hrs
Charge Algorithm	30% Depth of Discharge 50 Cycles, > 42Ah			Ending capacity 51Ah		

20 year maintenance free operation was demonstrated by performing life cycle testing. The life cycle testing consisted of 100% depth of discharge for 1000 cycles. The test data indicates that the new technology battery is capable of completing the goal of 1000 cycles while maintaining capacity above 42 Ah. The actual battery capacity at the end of the test was 55.7Ah or 1.4% lower than the new capacity of 56.5 Ah. Detailed results from this test are published in the referenced paper *(6)*, which is included as Appendix C.

Battery qualification testing was successfully completed as is documented in the Qualification Test Report *(7)*.

2.6 BCAU Test Results

BCAU DVT results are summarized in Table 2-4 and show that all design requirements are being met.

Table 2-4. BCAU DVT Summary

Test	Requirement		Results
Input Power Operation Range	Low Trip High Trip	225 +/- 5 V dc 305 +/- 5 V dc	221 V dc 304 V dc
Control Software Margins	Timing Memory	62.5ms frame time > 30% margin EPROM > 30% margin RAM	95% of frame time available 82% margin 88% margin
Output Power Quality	Regulation Vmode Regulation I mode Phase/Gain Margin Output Ripple Protection O/C, O/V	+/- 2% +/- 5% >30°., >6 dB <1Vpp 45 +/-3A, 39 +/- 1Vdc	+/- 1.3% +/- 3.1% 89°, 15 dB 0.4 Vpp 44.3 A, 39.5 V
Power Dissipation	Input Control Power Total	< 34 W < 1 W < 135 W < 170 W	29 W 1 W 133 W 163 W

The BCAU safety-of-flight qualification testing was successfully completed, with the exception of "Electromagnetic Compatibility" and "Phase Power Loss", as is documented in the Qualification Test Report *(7)*. Full compliance in these areas would require straightforward design changes.

2.7 Drawing and Hardware Deliveries

A complete Level II drawing package for the battery and BCAU was submitted to Wright Laboratory on 13 June 1997 via ELDEC Letter of Transmittal 97.0925LV8-774-01.

Eight batteries were shipped to Wright Laboratory on 23 May 1997 via ELDEC Packing Slip TNR052397A. Seven BCAU's were shipped to Wright Laboratory on 24 June 1997 via ELDEC Packing Slip TNR062497A.

2.8 Technology Transition

We are working with Wright Laboratory to use AMFABS in the Power Management and Distribution System for a More-Electric Aircraft (MADMEL). In addition, the E-3, E-8 and JAS-39 programs are considering upgrading to AMFABS.

3 CONCLUSION

The AMFABS program met or exceeded the original design goals:

- 20 year maintenance free capability
- Adaptability to all USAF aircraft
- State-of-health and state-of-charge
- Reduced size and weight

Flight worthy hardware is available at Wright Laboratory for flight testing.

The AMFABS program is supported by the USAF Wright Laboratory under contract F33615-91-C-2108. The authors would like to thank Mr. R. Flake, Mr. S. Vukson and Mr. R. Marsh at Wright Laboratory for their continued support on this project.

4 REFERENCES

1. *Technology Transition Study,* ELDEC Corporation, Lynnwood, WA, October 5, 1994

2. D. G. Vutetakis, "Current Status of Aircraft Batteries In the U. S. Air Force," *Proceedings of the Ninth Annual Battery Conference on Applications and Advances,* 1994

3. *BC2000B Prime Item Development Specification Advanced Maintenance-Free Aircraft Battery System - General Specification,* ELDEC Corporation, Lynnwood, WA, October 5, 1994

4. *BC2000/01 Prime Item Development Specification Advanced Maintenance-Free Aircraft Battery System - Detail Specification,* ELDEC Corporation, Lynnwood, WA, October 10, 1994

5. Z.W. Johnson, "Separator Qualification and Testing for Sealed Nickel-Cadmium Batteries," *Proceedings of the Eighth Annual Battery Conference on Applications and Advances,* 1993

6. T. Kulin & D. Scoles, "Life Cycle Testing of a Sealed 24-V, 42-Ah Nickel-Cadmium Aircraft Battery", 1996

7. *QTR8-774 Rev - Qualification Test Report for the Advanced Maintenance Free Aircraft Battery System (AMFABS),* ELDEC Corporation, Lynnwood, WA, 28 August 1998

APPENDIX A
BC-2000B PRIME ITEM DEVELOPMENT SPECIFICATION
(47 PAGES)

CRANE ELDEC CORPORATION

A SUBSIDIARY OF CRANE CO.

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ELDEC P/N:	8-774-01		
Customer P/N:			
Data Item No.:			

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–		Initial issue.

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1. SCOPE

This specification establishes the general performance, design, development, and test requirements for the Advanced Maintenance-Free Aircraft Battery System (AMFABS) prime item.

2. APPLICABLE DOCUMENTS

2.1 Government Documents

The following documents of the exact issue shown form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered as superseding requirements.

SPECIFICATIONS

Military

MIL-B-5087B Amendment 3 24 Dec 1984	Bonding, Electrical, and Lightning Protection for Aerospace Systems
MIL-E-5400T Amendment 3 14 May 1990	Electronic Equipment, Aerospace, General Specification for
MIL-P-6063B 22 Mar 1978	Packaging of Batteries, Storage, Charged and Dry, Uncharged and Moist, General Specification for
MIL-S-24236B Amendment 4 3 Jun 1991	Switches, Thermostatic, (Metallic and Bimetallic) General Specification for
MIL-B-81757C 1 Jul 1984	Batteries and Cells, Storage, Nickel-Cadmium, Aircraft, General Specification for

STANDARDS

Federal

FED-STD-595B 15 Dec 1989	Colors Used in Government Procurement

Military

DOD-STD-100D 3 Apr 1987	Engineering Drawing Practices
MIL-STD-129K 1 Jun 1988	Marking for Shipment and Storage
MIL-STD-130G 11 Oct 1988	Identification Marking of U.S. Military Property
MIL-STD-202F Notice 10 8 Jun 1990	Test Methods for Electronic and Electrical Component Parts

MIL-STD-454M Notice 2 3 Jun 1991	Standard General Requirements for Electronic Equipment
MIL-STD-461C Notice 2 15 Oct 1987	Electromagnetic Emission and Susceptibility, Requirements for the Control of Electromagnetic Interference
MIL-STD-462 Notice 6 15 Oct 1987	Electromagnetic Emission and Susceptibility, Test Methods for
MIL-STD-490A 4 Jun 1985	Specification Practices
MIL-STD-704E 1 May 1991	Aircraft Electric Power Characteristics
MIL-STD-756B Notice 1 31 Aug 1982	Reliability Modeling and Prediction
MIL-STD-785B Notice 2 5 Aug 1988	Reliability Program for Systems and Equipment Development and Production
MIL-STD-810E Notice 1 9 Feb 1990	Environmental Test Methods and Engineering Guidelines
MIL-STD-882B 30 Mar 1984	System Safety Program Requirements
MIL-STD-1472D Notice 1 20 Mar 1991	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
MIL-STD-2073-1 16 Jul 1984	DOD Material, Procedures for Development and Application of Packaging Requirements
DOD-STD-2167A 29 Feb 1988	Defense System Software Development
MIL-STD-45662A 1 Aug 1988	Calibration System Requirements

2.2 Non-Government Documents

Not applicable.

3. REQUIREMENTS

3.1 Prime Item Definition

The Advanced Maintenance-Free Aircraft Battery System, hereafter referred to as the system, shall consist of a sealed-cell nickel-cadmium battery and a microprocessor-controlled battery charger, with provisions for an optional display panel to annunciate system status information. The charger shall make use of state-of-the-art electronics technology to reduce weight and volume of the overall system, and shall have built-in-test capabilities for fault detection and isolation. The system shall be designed to operate for 20 years without scheduled flight-line maintenance. The detail requirements for the system shall be as specified herein and in accordance with the detail specification sheets developed for each target application.

3.1.1 Prime Item Diagram

The functional schematic of the system is diagrammed in Figure 3-1.

3.1.2 Interface Definition

The interface connections of the system shall be defined by the detail specification sheet.

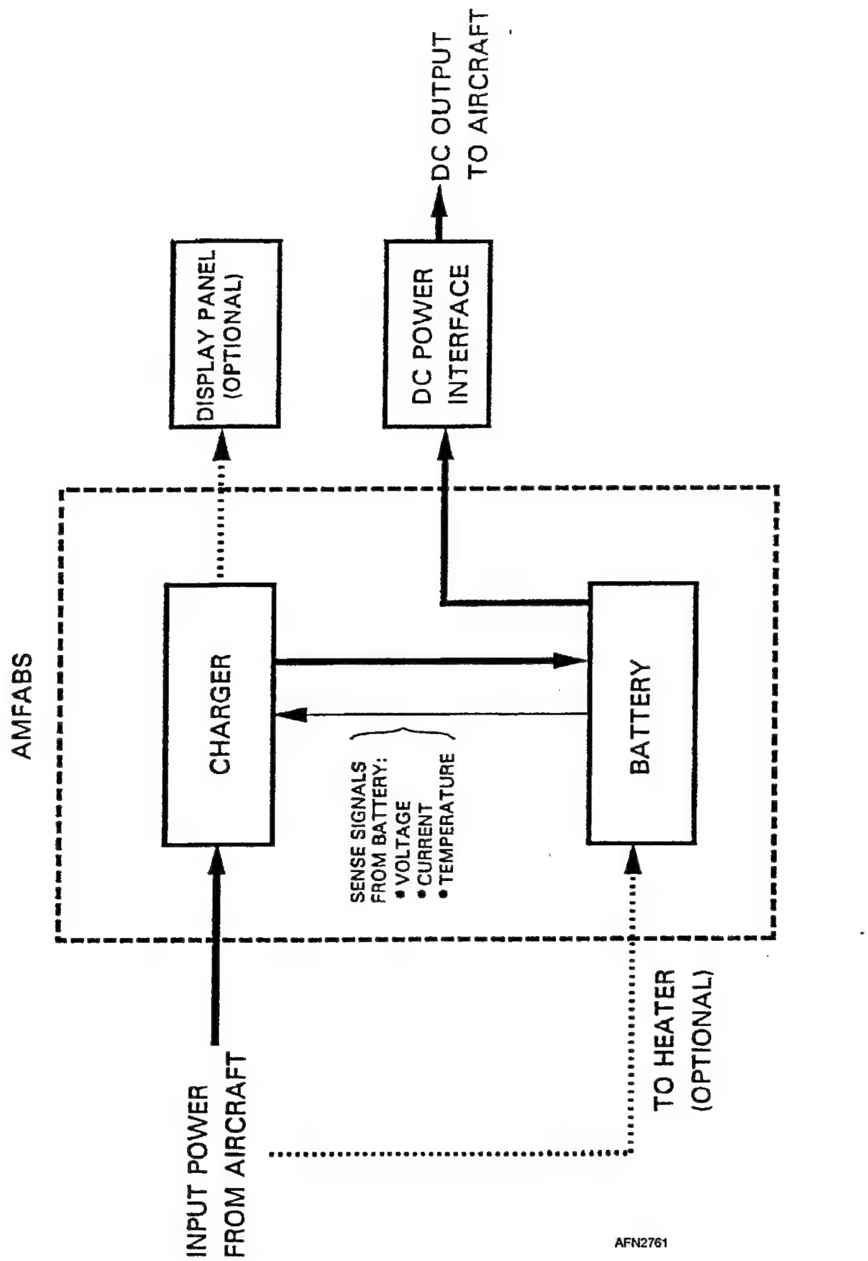

Figure 3–1
Prime Item Diagram

3.1.3 Major Component List

The system shall consist of the following major components:

Battery

a. Cells (quantity determined by voltage requirements)
b. Temperature sensor
c. Current sensor
d. Heater (optional)
e. Case and cover
f. Interface connector(s)

Charger

a. Input/Output module
b. Control/Built-in-test module
c. Power modules (quantity determined by power requirements)
d. Interface connector(s)

3.1.4 Government Furnished Property List.

Not applicable.

3.1.5 Government Loaned Property List

Not applicable.

3.2 Characteristics

3.2.1 Performance

The system shall conform to the performance requirements specified herein.

3.2.1.1 Battery

The battery shall comply with the performance requirements of MIL-B-81757, except as modified herein.

3.2.1.1.1 Nominal Voltage

The battery shall have a nominal voltage rating equivalent to 1.20 times the number of cells.

3.2.1.1.2 Capacity Rating

The capacity rating shall be as specified on the detail specification sheet. The capacity rating, in ampere-hours, shall be based on a 1-hour discharge rate (C-rate) at 25°C to an endpoint voltage of 0.9 times the number of cells. Capacity ratings may range from 1 to 100 ampere-hours.

3.2.1.1.3 Discharge Requirements

The battery shall comply with the discharge requirements specified in Table 3-1. When specified by the detail specification sheet, the high rate requirements of Table 3-2 shall also apply.

Table 3-1
Battery Discharge Requirements

Condition Number	Temperature (°C)	Discharge Rate (amperes)	Cutoff Voltage (volts)	Min. Discharge Time (minutes)
(1)	49	1C	18.0	50
(2)	25	1C	18.0	60
(3)	–18	1C	18.0	45
(4)	–40	1C	18.0	30

Table 3-2
Battery High Rate Requirement

Condition Number	Temperature (°C)	Discharge Rate (amperes)	Cutoff Voltage (volts)	Min. Discharge Time (minutes)
(1)	25	9C	14.4 (a)	5
(2)	–18	25C/5C (b)	18.0 (c)	1 (d)
(3)	–40	9C	13.0	1 (d)

(a) 17.0 volts minimum at 5 seconds

(b) The discharge rate for each 20-second pulse shall be 25C initially and shall decrease nearly to 5C over the 20-second time period.

(c) 12.0 volts minimum at 5 seconds after the beginning of each pulse.

(d) 3 pulses of 20 seconds each within 5 minutes.

3.2.1.1.4 Charge Retention

A fully charged battery shall deliver at least 50 percent of its rated capacity after storage for 7 days at 50°C. The battery shall then be capable of accepting a full charge at the normal rate.

3.2.1.1.5 Cycle Life

The battery shall deliver no less than 100 percent of rated capacity after 1000 cycles at 25 ± 5°C, with each cycle removing 100 percent of rated capacity at the one-hour rate.

3.2.1.1.6 Insulation Resistance

The insulation resistance between all mutually insulated terminals and case ground shall exceed 1 MΩ when tested at 500 ± 10 volts DC for one minute.

3.2.1.1.7 Dielectric Strength

The battery shall have a dielectric withstanding voltage of 750 ± 10 volts RMS at 50-60 Hz commercial frequency between all mutually insulated terminals and case ground. The leakage current after one minute shall not exceed 2 milliamperes.

3.2.1.1.8 Electrical Bonding

The electrical bond between case and connectors shall comply with MIL-B-5087, Class R (2.5 milliohms maximum).

3.2.1.2 Charger

3.2.1.2.1 Input Power

Unless otherwise specified, the charger shall utilize 3-phase, 400 Hz, 115/200 VAC electric power in accordance with MIL-STD-704 and shall comply with the utilization equipment requirements specified therein.

3.2.1.2.2 Rated Output

The maximum continuous output rating of the charger shall be as specified on the detail specification sheet.

3.2.1.2.3 Charging Rate

The charge rate shall be sufficient to meet the maximum charging times shown in Table 3-3, starting with a fully discharged battery (0.9 volt per cell).

Table 3-3
Maximum Charge Time

Temperature (°C)	To 80% of 1C Capacity (hours)	To 100 of 1C Capacity (hours)
49	1.5	3.0
25	1.0	2.0
–18	2.0	4.0
–40	2.5	5.0

3.2.1.2.4 Charge Regulation

The charger shall charge a battery from any initial state-of-charge to full capacity and then regulate the state-of-charge at no less than 80 percent of full capacity. The triggers for charge initiation and charge completion shall be as specified on the detail specification sheet.

3.2.1.2.5 Load Current During Charge

When required by the detail specification sheet, the charger shall meet the charge rate requirements (Paragraph 3.2.1.2.3) while supplying a specified load current. The value of the load current shall be as specified on the detail specification sheet.

3.2.1.2.6 Built-In-Test

The charger shall monitor the system to detect internal fault conditions. Detected faults shall be isolated to the line replaceable unit (LRU) level, and output signals to an external display panel shall be provided for annunciating the faulty LRU (e.g., battery or charger). Output signals shall be latched until the input power is recycled, and shall clear only if the fault condition no longer exists. Output signal characteristics shall be as specified on the detail specification sheet.

3.2.1.2.7 Battery Status

The charger shall monitor the battery's state-of-charge based on ampere-hour integration. The charger shall provide output signals to an external display panel for annunciating the battery status in terms of percent of full state-of-charge (0 to 100 percent scale). Output signal characteristics shall be as specified on the detail specification sheet.

3.2.1.2.8 Charger Disable

The output of the charger shall be disabled whenever one or more of the following fault conditions occurs:

a. Battery temperature greater than 80 ± 5°C or open contacts on battery thermal switch (see Paragraph 3.3.1.1.8).
b. Battery temperature less than –45 ± 5°C.
c. Loss of battery sense connections.
d. Internal failure of the charger resulting in loss of output control.

When the fault conditions are no longer present, the charger shall automatically return to normal operation.

3.2.1.2.9 Input Transients

The charger shall not be damaged or become unstable by exposure to the input voltage and frequency transients specified in Figures 6 and 7 of MIL-STD-704.

3.2.1.2.10 Voltage Spikes

The charger shall not be damaged by voltage spikes (pulse width less than 50 microseconds) up to a peak value of ± 200 volts superimposed on the supply voltage.

3.2.1.2.11 Phase Power Loss

The charger shall not be damaged or become unstable as a result of exposure to single or two phase operation.

3.2.1.2.12 Three–Phase Balance

The input power to the charger shall be balanced on each phase within the limits of Figure 1 of MIL-STD-704.

3.2.1.2.13 Short Circuit

The charger output shall not be damaged by any overload up to and including a short circuit condition.

3.2.1.2.14 Reverse Current

With no input power applied and with a simulated battery voltage of 32.0 ± 0.1 VDC applied to the output terminals, the charger shall sustain no damage and the reverse current shall not exceed 10 milliamperes.

3.2.1.2.15 Open Circuit

The charger shall not be damaged by operation into an open circuit at the output terminals with maximum input voltage applied.

3.2.1.2.16 Output Ripple

The ripple in the output voltage of the charger shall not exceed 1.5 volts peak-to-peak for frequencies less than 5 MHz.

3.2.1.2.17 Efficiency

The charger shall have a minimum efficiency of 80 percent with nominal input voltage and maximum rated output.

3.2.1.2.18 Insulation Resistance

The insulation resistance between all mutually insulated terminals and case ground shall exceed one megohm when tested at 500 ± 10 volts DC for one minute.

3.2.1.2.19 Dielectric Strength

The charger shall have a dielectric withstanding voltage of 750 ± 10 volts RMS at 50-60 Hz commercial frequency between all mutually insulated terminals and case ground. The leakage current after one minute shall not exceed 2 milliamperes.

3.2.1.2.20 Electrical Bonding

The electrical bond between case and connectors shall comply with MIL-B-5087, Class R (2.5 milliohms maximum).

3.2.1.3 Storage Life

The system shall be capable of storage at temperature conditions from –54°C to 38°C for at least 5 years without degrading the service life. The system shall require no maintenance during storage, and following the storage period it shall require no corrective maintenance. The battery may be stored in a discharged condition, but it must deliver no less than rated capacity after being reconditioned in accordance with the manufacturer's instructions.

3.2.1.4 Service Life

The system shall be designed to have a service life of at least 20 years when operated under the environmental conditions specified herein.

3.2.2 Physical Characteristics.

3.2.2.1 Weight

The maximum weight of the battery and charger shall be as specified on the detail specification sheet.

3.2.2.2 Size

Outline dimensions of the battery and charger shall be as specified on the detail specification sheet.

3.2.2.3 Mounting Provisions

Mounting provisions for the battery and charger shall be as specified on the detail specification sheet.

3.2.2.4 Operating Position

The system shall be capable of operating in any position without performance degradation. For passively cooled chargers, thermal design shall be based on operation in the upright position only.

3.2.3 Reliability

When operated within the environmental limits specified herein, the system shall have a predicted mean-time-between-failure of at least 20,000 operational hours using applicable modeling and prediction methods of MIL-STD-756. Failure is defined as inability to meet specified performance requirements.

3.2.4 Maintainability

3.2.4.1 On-aircraft

The system shall not require any scheduled maintenance, such as reconditioning, electrolyte addition, parts replacement, calibrations, or adjustments, while installed on the aircraft. Faults that occur while the system is installed shall be detected by built-in-test per Paragraph 3.2.1.2.6 and isolated to the line replaceable unit (battery LRU or charger LRU).

3.2.4.2 Off-aircraft

The system shall be designed to provide for repair of failed shop replaceable units (SRUs) through removal and replacement actions. Test points shall be provided to allow rapid fault isolation at the SRU level. To prevent cell imbalance within the battery, replacement of individual cells shall not be permitted as a means of repair (see Paragraph 3.5.1).

3.2.5 Environmental Conditions

The system shall meet all specified performance requirements when exposed to the environmental conditions specified in Paragraphs 3.2.5.1 through 3.2.5.12. When subjected to the specified environmental conditions, the system shall not show:

a. Dimensional distortion beyond specified limits
b. Mechanical failure of any part
c. Degradation of electrical performance beyond specified limits

d. Spilling or leakage of electrolyte, or venting of cells

e. Breakdown of insulation, stripping of metal plating from any component part, corrosion of metal parts, or loosening of protective coatings from any part

f. Deterioration of identification markings

g. Fungus growth.

3.2.5.1 Temperature

The system shall withstand exposure to operating and non-operating temperature conditions specified in Table I of MIL-E-5400 for Class 2 equipment, except the lower continuous operational limit for the battery shall be –40°C and the upper non–operational limit for the battery shall be 71°C. For passively cooled chargers, the output may be derated during intermittent operation at temperatures above 71°C.

3.2.5.2 Altitude

The system shall withstand exposure to operating and non–operating altitude conditions specified in Table I of MIL-E-5400 for Class 2 equipment. For passively cooled chargers, the output may be derated at maximum altitude conditions.

3.2.5.3 Temperature-Altitude Combination

The system shall withstand exposure to the temperature-altitude combinations specified in Table I of MIL-E-5400 for Class 2 equipment, except the lower temperature limit for the battery shall be –40°C. For passively cooled chargers, the output may be derated at maximum altitude conditions.

3.2.5.4 Temperature Shock

The system shall withstand exposure to the temperature shock conditions specified in Table I of MIL-E-5400 for Class 2 equipment, except that the upper temperature limit for the battery shall be 71°C.

3.2.5.5 Vibration

The system shall withstand exposure to vibration conditions induced by the aircraft environment in which it is installed. The applicable vibration environment shall be determined from Paragraph 3.2.24.5 of MIL-E-5400 or as specified on the detail specification sheet. The charger SRUs shall be designed to withstand the vibration levels of MIL-STD-810, Figure 514.4-8, with W_o equal to 0.3 g^2/Hz (20 gs RMS).

3.2.5.6 Mechanical Shock

The system shall withstand exposure to the mechanical shock conditions specified in Paragraph 3.2.24.6 of MIL-E-5400, or as specified on the detail specification sheet.

3.2.5.7 Acceleration

The system shall withstand exposure to acceleration forces induced by the aircraft environment in which it is installed. The applicable acceleration environment shall be determined from the guidelines given in Method 513 of MIL-STD-810, or as specified on the detail specification sheet.

3.2.5.8 Explosive Atmosphere

Operation of the system shall not cause ignition of an explosive mixture of fuel in air.

3.2.5.9 Humidity

The system shall withstand exposure to relative humidity levels up to 100 percent, including conditions wherein condensation takes place in and on the equipment.

3.2.5.10 Salt fog

The system shall withstand exposure to salt fog and spray conditions as found in marine environments.

3.2.5.11 Sand and Dust

The system shall withstand exposure to sand and dust conditions as found in marine and desert environments.

3.2.5.12 Fungus

The system shall withstand exposure to fungus conditions as found in tropical environments.

3.2.6 Transportability

The system shall accommodate handling, loading, securing, and shipping within existing capabilities of military and commercial carriers.

3.3 **Design and Construction.**

3.3.1 **Materials, Processes and Parts**

3.3.1.1 **Battery**

The battery design shall comply with the requirements of MIL-E-5400, MIL-STD-454, and the additional requirements specified herein.

3.3.1.1.1 **Cells**

The battery shall contain N nickel-cadmium cells electrically connected in series, where N is the number of cells specified on the detail specification sheet. The cells shall be securely mounted within the battery case.

3.3.1.1.2 **Cell Container**

Each cell shall be sealed against the loss of gases and electrolyte under all normal operating conditions. The cell container shall be capable of withstanding internal pressures of at least 100 psig without leakage when assembled in the battery case. There shall be no evidence of electrolyte leakage, such as carbonate deposits, over the life of the battery.

3.3.1.1.3 **Cell Venting**

Each cell shall contain a vent valve or rupture disk to prevent the internal cell pressure from exceeding 80 psig. Cell venting shall not occur below 40 psig.

3.3.1.1.4 **Intercell Links**

Intercell links shall be fastened to the cell terminals so that periodic maintenance, such as retorquing of terminal nuts or screws, is not required over the life of the battery. The intercell links shall have sufficient cross-sectional area to withstand a full discharge at any rate the battery is capable of delivering.

3.3.1.1.5 **Temperature Sensor**

The battery shall contain a temperature sensor to measure the average cell temperature for use by the charger. The temperature sensor characteristics shall be as specified on the detail specification sheet.

3.3.1.1.6 Current Sensor

The battery shall contain a current sensor to measure the DC current levels passing through the battery for use by the charger. The current sensor characteristics shall be as specified on the detail specification sheet.

3.3.1.1.7 Heater

When specified on the detail specification sheet, a heater shall be incorporated in the battery to improve performance under extreme low temperature conditions. The heater circuit shall be equipped with redundant thermostatic switches conforming to MIL-S-24236 for temperature control. The input voltage and maximum allowable heater current shall be as specified on the detail specification sheet.

3.3.1.1.8 Thermal Switch

When specified on the detail specification sheet, a thermal switch shall be incorporated in the battery to detect an overtemperature condition. The contacts shall be normally closed and shall open at the temperature value specified in the detail specification sheet.

3.3.1.1.9 Battery Case

The battery case shall be of sufficient strength to maintain the specified dimensional tolerances over the life of the battery. Unless otherwise specified on the detail specification sheet, the case color shall be blue within the range of color numbers 15090 to 15193 per FED-STD-595. The battery case shall contain a vent mechanism to prevent excessive pressure build-up in the event that gases are released from one or more cells. The case shall be equipped with a removable cover to provide access to replaceable parts and subassemblies.

NOTE

CELLS ARE NOT CONSIDERED REPLACEABLE - SEE PARAGRAPH 3.5.1.

3.3.1.1.10 Receptacles

Receptacles on the battery container for external electrical connections shall be as specified in the detail specification sheet.

3.3.1.2 Charger

The charger design shall comply with the requirements of MIL-E-5400, MIL-STD-454, and the additional requirements specified herein.

3.3.1.2.1 Software Development

Software development for the microprocessor shall comply with DOD-STD-2167.

3.3.1.2.2 Thermal Design

Thermal design shall comply with MIL-STD-454, Requirement 52. Unless otherwise specified on the detail specification sheet, the charger shall be designed to operate with natural convection cooling.

3.3.1.2.3 Charger Case

The charger case shall be of sufficient strength to maintain the specified dimensional tolerances over the life of the charger. Unless otherwise specified on the detail specification sheet, the charger color shall be lusterless black.

3.3.1.2.4 Receptacles

Receptacles on the charger for external electrical connections shall be as specified on the detail specification sheet.

3.3.1.2.5 Standard Power Modules

SRUs for the charger shall be designed in accordance with a "standard power module" concept. The outline dimensions of each module shall fall within the limits of 7.64 inches high and 7.50 inches wide. The depth of the module shall vary depending on the power rating and cooling provisions. All modules shall plug into a common signal bus and be independently removable.

3.3.2 Electromagnetic Radiation

The charger shall be designed to control electromagnetic interference and shall meet the electromagnetic emission and susceptibility requirements of MIL-STD-461 for Class A1b equipment. The charger shall meet the requirements of CE03, CE07, CS01, CS02, CS06, RE02, RS02, and RS03.

3.3.3 Nameplates and Product Markings

Nameplates and product marking shall comply with MIL-STD-130. Labeling location shall be as specified on the detail specification sheet.

3.3.3.1 Battery Nameplate

The battery nameplate shall contain the following information, as a minimum:

Battery Storage, Nickel-Cadmium, Aircraft, Maintenance-Free
Rated Capacity
Nominal Voltage
Maximum Weight
Manufacturer's Part Number
Contract Number
Date of Manufacture
Serial Number
Manufacturer's Name

3.3.3.2 Battery Terminals

The battery case shall have indelible markings to identify the positive and negative terminals.

3.3.3.3 Battery Installation Date

The battery case shall contain the following label to allow the date of initial installation to be recorded:

FIRST PLACED IN SERVICE
DATE __**__

** Leave blank, surface prepared as required to allow for stamping or printing.

3.3.3.4 Battery Cover Marking

The battery cover shall be marked with the following instructions:

MAINTENANCE-FREE NICKEL-CADMIUM AIRCRAFT BATTERY
PROCESS WITH APPROVED PROCEDURES ONLY
THE CELLS IN THIS BATTERY ARE NOT TO BE REMOVED

3.3.3.5 Cell Terminals

Each cell shall have indelible markings to identify the positive and negative terminals.

3.3.3.6 Charger Nameplate

The charger nameplate shall contain the following information, as a minimum:

Charger, Battery, Nickel-Cadmium, Aircraft
Input Rating
Output Rating
Maximum Weight
Manufacturer's Part Number
Contract Number
Date of Manufacture
Serial Number
Manufacturer's Name

3.3.3.7 Charger Terminals

The charger case shall have indelible markings to identify the positive and negative terminals.

3.3.4 Workmanship

The system shall be manufactured in accordance with Requirement 9 of MIL-STD-454. The system shall be free of defects that will affect life, performance and appearance.

3.3.5 Interchangeability

Interchangeability of parts and subassemblies within the system shall comply with Requirement 7 of MIL-STD-454.

3.3.6 Safety

The system shall be designed in accordance with MIL-STD-454, Requirement 1 and MIL-STD-882, Paragraph 4.

3.3.7 Human Performance/Human Engineering

The system shall be designed in accordance with MIL-STD-1472.

3.3.8 Environmental Stress Screening (ESS)

Burn-in testing shall be accomplished on all chargers prior to acceptance in accordance with MIL-STD-785, Task 301.

3.4 Documentation

Documentation requirements shall be as specified in the Contract Data Requirements List.

3.5 Logistics

3.5.1 Maintenance

The battery and charger shall each be considered a line replaceable unit (LRU). Organizational level maintenance shall consist of LRU fault verification, LRU removal and replacement, and preflight/postflight inspections. Repair of the battery and charger shall consist of fault isolating the LRU to the shop replaceable module (SRU) level, and replacement of defective or failed SRUs. Cells within the battery shall not be considered SRUs. In the event of failed cells, the battery shall be returned to the manufacturer for overhaul or replacement.

3.5.2 Supply

Supply and distribution methods for the system shall be the same as those established for other types of aircraft battery systems.

3.5.3 Facilities and Facility Equipment

New facilities and equipment shall not be required to support the system at the LRU level. Test equipment at the SRU level shall not be considered part of this specification.

3.6 Personnel and Training

3.6.1 Personnel

Personnel requirements shall not exceed the skill levels that presently exist for operators and maintainers of aircraft battery systems.

3.6.2 Training

The system shall not require special training of operational and maintenance personnel.

3.7 Major Component Characteristics

The major components listed in Paragraph 3.1.3 shall meet the performance and physical requirements specified herein and in the detail specification sheet.

3.8 Precedence

The requirements of this specification shall follow the following order of preference:

a. Safety
b. Performance and physical characteristics
c. Reliability and maintainability
d. Workmanship
e. All others.

In the event of conflict between the referenced documents and the contents of this specification, the contents of this specification shall govern.

4 QUALITY ASSURANCE PROVISIONS

4.1 General

The system shall be subjected to quality assurance provisions to verify compliance with Section 3 of this specification.

4.1.1 Responsibility for Verification

Unless otherwise specified in the contract or order, the contractor is responsible for the performance of all verification requirements as specified herein. Except as otherwise specified, the contractor may utilize his own facilities or any commercial laboratory acceptable to the contracting agency. The contracting agency reserves the right to perform any of the verifications set forth in this specification where such examinations are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.2 Methods of Verification

All requirements specified in Section 3 shall be verified by inspection, analysis, demonstration, or test. Table 4-1 lists the verification cross-reference index and correlates each Section 3 requirement with the corresponding Section 4 method of verification. The verification methods are defined as follows:

a. Inspection – Verification by visual examination or physical measurements of the item without use of special laboratory equipment or procedures.

b. Analysis – Verification by technical evaluation using mathematical representations, charts, graphs, circuit diagrams, reduced data and/or representative data.

c. Demonstration. Verification by operation, movement, and/or adjustment of the item under specific conditions to perform the design function without recording of data.

d. Test – Verification through systematic exercising of the item under appropriate conditions with instrumentation to measure required parameters and the collection, analysis and evaluation of quantitative data to show that measured parameters comply with specified requirements.

Table 4-1
Verification Cross-Reference Index

Requirement Paragraph	Paragraph Title	Verification Method	Verification Paragraph
3.1	Prime item definition	NA	NA
3.1.1	Prime item diagram	NA	NA
3.1.2	Interface definition	NA	NA
3.1.3	Major component list	NA	NA
3.1.4	Government furnished property list	NA	NA
3.1.5	Government loaded property list	NA	NA
3.2	Characteristics	NA	NA
3.2.1	Performance	NA	NA
3.2.1.1	Battery	NA	NA
3.2.1.1.1	Nominal voltage	I	4.3.1
3.2.1.1.2	Capacity rating	T	4.6.1.1.5
3.2.1.1.3	Discharge reqiurements	T	4.6.1.1.5
3.2.1.1.4	Charge retention	T	4.6.1.1.8
3.2.1.1.5	Cycle life	T	4.6.1.1.7
3.2.1.1.6	Insulation resistance	T	4.6.1.1.2
3.2.1.1.7	Dielectric strength	T	4.6.1.1.3
3.2.1.1.8	Electrical bonding	T	4.6.1.1.4
3.2.1.2	Charger	NA	NA
3.2.1.2.1	Input power	T	4.6.1.3.1, 4.6.1.3.2
3.2.1.2.2	Rated output	T	4.6.1.2.6
3.2.1.2.3	Charging rate	T	4.6.1.3.5
3.2.1.2.4	Charge regulation	T	4.6.1.3.6
3.2.1.2.5	Load current during charge	T	4.6.1.3.5
3.2.1.2.6	Built–in–test	D	4.5.1
3.2.1.2.7	Battery status	D	4.5.2
3.2.1.2.8	Charge diable	T	4.6.1.2.13
3.2.1.2.9	Input transients	T	4.6.1.3.2
3.2.1.2.10	Voltage spikes	T	4.6.1.3.3
3.2.1.2.11	Phase power loss	T	4.6.1.3.4
3.2.1.2.12	Three–phase balance	T	4.6.1.2.9
3.2.1.2.13	Short circuit	T	4.6.1.2.10
3.2.1.2.14	Reverse current	T	4.6.1.2.11
3.2.1.2.15	Open circuit	T	4.6.1.2.12
3.2.1.2.16	Output ripple	T	4.6.1.2.8
3.2.1.2.17	Efficiency	T	4.6.1.2.7
3.2.1.2.18	Insulation resistance	T	4.6.1.2.1
3.2.1.2.19	Dielectric strength	T	4.6.1.2.2
3.2.1.2.20	Electrical bonding	T	4.6.1.2.3
3.2.1.3	Storage life	A	4.4
3.2.1.4	Service life	A	4.4
3.2.2	Physical characteristics	NA	NA
3.2.2.1	Weight	I	4.4.2
3.2.2.2	Size	I	4.4.2
3.2.2.3	Mounting Provisions	I	4.4.2

Requirement Paragraph	Paragraph Title	Verification Method	Verification Paragraph
3.2.2.4	Operating position	T	4.6.1.1.6, 4.6.1.3.7
3.2.3	Reliability	A and T	4.4, 4.6.3
3.2.4	Maintainability	MA	NA
3.2.4.1	On–Aircraft	A	4.4
3.2.4.2	Off–Aircraft	A	4.4
3.2.5	Environmental conditions	NA	4.6.2
3.2.5.1	Temperature	T	4.6.2.1, 4.6.2.2
3.2.5.2	Altitude	T	4.6.2.3
3.2.5.3	Temperature–altitude combination	T	4.6.2.3
3.2.5.4	Temperature shock	T	4.6.2.4
3.2.5.5	Vibration	T	4.6.2.5
3.2.5.6	Mechanical shock	T	4.6.2.6
3.2.5.7	Acceleration	A or T	4.4, 4.6.2.7
3.2.5.8	Explosive atmosphere	A or T	4.4, 4.6.2.8
3.2.5.9	Humidity	T	4.6.2.9
3.2.5.10	Salt fog	T	4.6.2.10
3.2.5.11	Sand and dust	A or T	4.4, 4.6.2.11
3.2.5.12	Fungus	A	4.4
3.2.6	Transportability	A	4.4
3.3	Design and construction	NA	NA
3.3.1	Materials, processes and parts	NA	NA
3.3.1.1	Battery	NA	NA
3.3.1.1.1	Cells	A	4.4
3.3.1.1.2	Cell container	T	4.6.1.1.1
3.3.1.1.3	Cell venting	T	4.6.1.1.1
3.3.1.1.4	Intercell links	A	4.4
3.3.1.1.5	Temperature sensor	A	4.4
3.3.1.1.6	Current sensor	A	4.4
3.3.1.1.7	Heater	T	4.6.1.1.9
3.3.1.1.8	Thermal switch	A	4.4
3.3.1.1.9	Battery case	I	4.3.1
3.3.1.1.10	Receptacles	I	4.3.1
3.3.1.2	Charger	NA	NA
3.3.1.2.1	Software development	A and T	4.4, 4.6.1.2.14
3.3.1.2.2	Thermal design	A and T	4.4, 4.6.2.1, 4.6.2.3
3.3.1.2.3	Charger case	I	4.3.1
3.3.1.2.4	Receptacles	I	4.3.1
3.3.1.2.5	Standard electronic modules	A	4.4
3.3.2	Electromagnetic radiation	T	4.6.1.2.4
3.3.3	Nameplates and product markings	I	4.3.1
3.3.3.1	Battery nameplate	I	4.3.1
3.3.3.2	Battery terminals	I	4.3.1
3.3.3.3	Battery installation date	I	4.3.1
3.3.3.4	Battery cover marking	I	4.3.1
3.3.3.5	Cell terminals	I	4.3.1
3.3.3.6	Charger nameplate	I	4.3.1

Requirement Paragraph	Paragraph Title	Verification Method	Verification Paragraph
3.3.3.7	Charger terminals	I	4.3.1
3.3.4	Workmanship	I	4.3.1
3.3.5	Interchangeability	A	4.4
3.3.6	Safety	A	4.4
3.3.7	Human performance/human engineering	A	4.4
3.3.8	Environmental stress screening	T	4.6.1.2.5

4.1.3 Qualification

Qualification shall consist of the inspections, analyses, demonstrations and tests specified in Table V performed on qualification samples to verify that the system complies with all specification requirements.

4.1.3.1 Test Samples

Test samples shall be representative of the items proposed to be furnished for aircraft installation. Each test sample shall be permanently marked "Qualification Sample".

4.1.3.2 Similarity

Partial fulfillment of qualification requirements on the basis of similarity of the item to previously qualified items is permissible under the following conditions:

a. Certified data substantiate that a similar item has been qualified to an equivalent requirement.

b. The item being qualified does not incorporate differences that would invalidate the criteria of (a).

The contractor is responsible for providing the documentation satisfying the above criteria.

4.1.3.3 Safety-of-Flight Tests

Safety-of-flight tests shall verify the safety and airworthiness of the system prior to flight trials, and shall consist of a subset of the qualification tests as specified in Table V. Safety-of-flight tests shall be performed only when full qualification cannot be completed prior to aircraft installation. If conducted, results from safety-of-flight testing shall be used wherever possible to satisfy qualification requirements.

4.1.3.4 Certification

Successful completion of safety-of-flight tests shall be certified prior to delivery of the first system for aircraft installation. In the event that qualification tests are completed prior to aircraft installation, the requirement for safety-of-flight testing will be waived and safety-of-flight certification shall be based on the results of qualification tests.

4.1.4 Acceptance Tests

Acceptance tests and inspections as specified in Table 4-2 shall be performed on each system produced to verify acceptable performance and quality conformance. Separate acceptance test procedures (ATPs) shall be prepared for the battery and charger. These tests do not relieve the contractor of the responsibility for performing any additional tests or inspections which are necessary to control the quality of the product.

Table 4-2
Qualification and Acceptance Requirements

Paragraph	Title	Qualification	Safety-Of-Flight	Acceptance
4.3	INSPECTIONS			
4.3.1	Visual examination	X	X	X
4.3.2	Dimensions and weight	X	X	X
4.4	ANALYSES	All Items	Items e,f,l	
4.5	DEMONSTRATIONS			
4.5.1	Built–in–test	X		
4.5.1	Battery status	X		
4.6	TESTS			
4.6.1	Performance Tests			
4.6.1.1	Battery			
4.6.1.1.1	Cell test	X	X	
4.6.1.1.2	Insulation resistance	X	X	X
4.6.1.1.3	Dielectric strength	X	X	X
4.6.1.1.4	Connector bonding	X	X	
4.6.1.1.5	Discharge performance	X	X	X
4.6.1.1.6	Discharge while inverted	X	X	
4.6.1.1.7	Cycle life	X		
4.6.1.1.8	Charge retention	X		
4.6.1.1.9	Heater test	X	X	
4.6.1.2	Charger			
4.6.1.2.1	Insulation resistance	X	X	X
4.6.1.2.2	Dielectric strength	X	X	X
4.6.1.2.3	Connector bonding	X	X	
4.6.1.2.4	Electromagnetic compatibility	X	X	
4.6.1.2.5	Environmental stress screening			X
4.6.1.2.6	Operational test	X	X	X
4.6.1.2.7	Efficiency	X	X	X
4.6.1.2.8	Output ripple	X	X	X
4.6.1.2.9	Three–phase balance	X	X	

Paragraph	Title	Qualification	Safety-Of-Flight	Acceptance
4.6.1.2.10	Short circuit test	X	X	
4.6.1.2.11	Reverse current test	X	X	X
4.6.1.2.12	Open circuit test	X	X	X
4.6.1.2.13	Charger disable	X	X	X
4.6.1.2.14	Software verification	X	X	
4.6.1.3	System			
4.6.1.3.1	Normal AC input	X	X	
4.6.1.3.2	Abnormal AC input	X	X	
4.6.1.3.3	Input voltage spikes	X	X	
4.6.1.3.4	Phase power loss	X	X	
4.6.1.3.5	Charge time	X	X	
4.6.1.3.6	Charge regulation	X	X	
4.6.1.3.7	Operating position	X	X	
4.6.2	Environmental Tests			
4.6.2.1	High temperature	X	X	
4.6.2.2	Low temperature	X	X	
4.6.2.3	Altitude	X	X	
4.6.2.4	Temperature shock	X		
4.6.2.5	Vibration	X	X	
4.6.2.6	Mechanical shock	X	X	
4.6.2.7	Acceleration	X	X	
4.6.2.8	Explosive atmosphere	X	X	
4.6.2.9	Humidity	X		
4.6.2.10	Salt fog	X		
4.6.2.11	Sand and dust	X		
4.6.3	Reliability test	X		

4.2 Measurement Conditions and Equipment

4.2.1 Ambient Conditions

Unless otherwise specified herein, all measurements and tests shall be made at an ambient temperature of 25 ± 5°C under prevailing atmospheric pressure and relative humidity conditions.

4.2.2 Low and High Temperature Conditions

Low and high temperature tests shall be performed with the test unit stabilized at the specified temperature within ± 5°C. The item temperature shall be considered stabilized when the temperature of the part with the longest thermal lag is changing no more than 5°C per hour.

4.2.4 Instrument Accuracy

Voltmeters, ammeters and ohmmeters shall be accurate to at least ± 1.0 percent of the full scale reading. Time measurements shall be accurate to ± 1.0 percent of the total time period specified.

4.2.5 Instrument Calibration

All measuring and test equipment shall be calibrated in accordance with MIL-C-45662.

4.2.6 Equipment Orientation

Unless otherwise specified, the unit under test shall be positioned base down during test and rest periods.

4.2.7 Mounting

For vibration, shock and acceleration tests, the unit under test shall be mounted by normal aircraft attachment points.

4.2.8 Charger Input

Unless otherwise specified, a standard three–phase input voltage of 115 ± 3 volts RMS line-to-neutral and a standard frequency of 400 ± 4 Hz shall be applied during operation of the charger.

4.2.9 Discharge Conditions

The battery shall be discharged using a suitable load bank capable of maintaining the current within ± 5 percent of the specified value. Unless otherwise stated, all discharges shall start with the battery fully charged per the manufacturer's instructions and the discharge period shall be continuous.

4.2.10 Electrical Interface

The system shall be electrically interconnected in a manner that simulates the aircraft installation.

4.3 Inspections

4.3.1 Visual Examination

The units shall be visually examined to verify that the design and construction conform to the requirements specified below. The units shall not be disassembled for this examination.

a. Nominal voltage (3.2.1.1.1)
b. Battery case and receptacle (3.3.1.1.9 and 3.3.1.1.10)
c. Charger case and receptacle (3.3.1.2.3 and 3.3.1.2.4)
d. Nameplates and product marking (3.3.3 and subparagraphs)
e. Workmanship (3.3.4).

4.3.2 Dimensions and Weight

The units shall be measured and weighed to determine compliance with the requirements of Paragraphs 3.2.2.1 through 3.2.2.3.

4.4 Analyses

The following requirements shall be verified by analysis using applicable engineering data and handbooks.

a. Storage life (3.2.1.3)
b. Service life (3.2.1.4)
c. Reliability (3.2.3)
d. Maintainability (3.2.4 and subparagraphs)
e. Acceleration (3.2.5.7)
f. Explosive atmosphere (3.2.5.8)
g. Sand and dust (3.2.5.11)
h. Fungus (3.2.5.12)
i. Transportability (3.2.6)
j. Materials, processes and parts (Paragraphs 3.3.1.1.1, 3.3.1.1.4, 3.3.1.1.5, 3.3.1.1.6, 3.3.1.1.8, 3.3.1.2.1, 3.3.1.2.2, and 3.3.1.2.5)
k. Interchangeability (3.3.5)
l. Safety (3.3.6)
m. Human performance/human engineering (3.3.7)
n. Logistics (3.5 and subparagraphs)
o. Personnel and training (3.6 and subparagraphs).

Items e through g may be verified by the applicable test paragraph in lieu of analysis (see Paragraphs 4.6.2.7, 4.6.2.8, and 4.6.2.11).

4.5 Demonstrations

4.5.1 Built-in-Test

The built-in-test function shall be demonstrated by injecting typical fault conditions and monitoring the charger for correct indications.

4.5.2 Battery Status

The battery state-of-charge function shall be demonstrated by performing multiple discharge/charge cycles and monitoring the charger for correct indications.

4.6 Tests

4.6.1 Performance Tests

4.6.1.1 Battery

4.6.1.1.1 Cell Test

Individual cells shall be pressure tested to verify compliance with the requirements of Paragraphs 3.3.1.1.2 and 3.3.1.1.3.

4.6.1.1.2 Insulation Resistance

The battery shall be subjected to an insulation resistance (IR) test per MIL-STD-202, Method 302. A test voltage of 500 ± 10 volts DC shall be applied between all mutually insulated terminals and case for one minute. The measured resistance shall be greater than 1MΩ.

4.6.1.1.3 Dielectric Strength

The battery shall be subjected to a dielectric withstanding voltage (DWV) test per MIL-STD-202, Method 301. A test voltage of 750 ± 10 volts RMS at 60 Hz commercial frequency shall be applied between all mutually insulated terminals and case for one minute. There shall be no evidence of breakdown or flashover, and the leakage current shall not exceed 2 milliamperes. The IR test (see Paragraph 4.6.1.1.2) shall be performed before and after the DWV test.

4.6.1.1.4 Connector Bonding

The direct current (DC) impedance between connector shell and case shall be measured to verify compliance with Paragraph 3.2.1.1.8. The measured impedance shall not exceed 2.5 milliohms.

4.6.1.1.5 Discharge Performance

The battery shall be discharged under each condition specified in Table I. When specified in the detail specification sheet, the battery also shall be subjected to the high rate conditions of Table II. The battery shall supply no less than the minimum discharge time above the specified cutoff voltages. For acceptance tests, the battery only needs to be discharged under condition (2) of Table I and, as applicable, condition (1) of Table II.

4.6.1.1.6 Discharge While Inverted

The battery shall be discharged under conditions (2) and (3) of Table I while inverted. The battery shall supply no less than the minimum discharge time above the specified cutoff voltages.

4.6.1.1.7 Cycle Life

The battery shall be subjected to 1000 cycles of discharge and charge while maintaining the battery's average temperature at 25 ± 5°C. Each cycle shall consist of a C-rate discharge for one hour, followed by a two hour charge period, followed by three hour rest period (6 hour cycle time). After completion of the cycles, the battery must deliver at least 100 percent of rated capacity.

4.6.1.1.8 Charge Retention

The battery shall be fully charged, then stabilized at 50°C for a period of 7 days. After cooldown and stabilization at room temperature, the battery shall deliver at least 50 percent of rated capacity.

4.6.1.1.9 Heater Test

When the battery contains a heater, a test shall be performed to verify the heater performance. This test shall be as specified on the detail specification sheet.

4.6.1.2 Charger

4.6.1.2.1 Insulation Resistance

The charger shall be subjected to an insulation resistance (IR) test per MIL-STD-202, Method 302. A test voltage of 500 ± 10 volts DC shall be applied between all mutually insulated terminals and case for one minute. The measured resistance shall be greater than 1MΩ.

NOTE

THIS TEST MAY BE CONDUCTED PRIOR TO FINAL ASSEMBLY TO AVOID DAMAGE TO THOSE COMPONENTS NOT RATED TO WITHSTAND THE APPLIED VOLTAGE.

4.6.1.2.2 Dielectric Strength

The charger shall be subjected to a dielectric withstanding voltage (DWV) test per MIL-STD-202, Method 301. A test voltage of 750 ± 10 volts RMS at 60 Hz commercial frequency shall be applied between all mutually insulated terminals and case for one minute. There shall be no evidence of breakdown or flashover, and the leakage current shall not exceed 2 milliamperes. The IR test (see Paragraph 4.6.1.2.1) shall be performed before and after the DWV test.

NOTE

THIS TEST MAY BE CONDUCTED PRIOR TO FINAL ASSEMBLY TO AVOID DAMAGE TO THOSE COMPONENTS NOT RATED TO WITHSTAND THE APPLIED VOLTAGE.

4.6.1.2.3 Connector Bonding

The direct current (DC) impedance between connector shell and case shall be measured to verify compliance with Paragraph 3.2.1.2.21. The measured impedance shall not exceed 2.5 milliohms.

4.6.1.2.4 Electromagnetic Compatibility

The charger shall be tested in accordance with MIL-STD-462 to verify compliance with Paragraph 3.3.2.

4.6.1.2.5 Environmental Stress Screening

The charger shall be subjected to ESS in accordance with the requirements of Paragraph 3.3.8. The ESS regimen shall be tailored based on 1) analysis of thermal and vibration surveys and 2) estimation of the number and type of defects expected.

4.6.1.2.6 Operational Test

The charger shall be operated in all applicable operating modes. The triggers for charge initiation and completion per Paragraph 3.2.1.2.4 shall be verified.

4.6.1.2.7 Efficiency

The charger efficiency shall be measured at full rated output and nominal input voltage. The efficiency shall not be less than 80 percent. For acceptance tests, the charger input current may be measured as a means verifying efficiency.

4.6.1.2.8 Output Ripple

The charger shall be operated at no load and full load to verify that the output ripple voltage at the charger terminals does not exceed 1.5 volts peak-to-peak for frequencies less than 5 MHz.

4.6.1.2.9 Three-Phase Balance

The input phase imbalance shall be measured over the full range of normal steady-state input power conditions and with full rated output. The phases shall be balanced within the limits specified in Figure 1 of MIL-STD-704.

4.6.1.2.10 Short Circuit Test

The charger output shall be short circuited, with maximum input voltage applied, for a period of one hour. The short circuit shall be removed and reapplied at least 5 times during the test. The charger shall sustain no damage.

NOTE

FOR ACCEPTANCE TESTS, THE TIME PERIOD MAY BE SHORTENED AS NECESSARY TO REDUCE OVERALL TEST TIME.

4.6.1.2.11 Reverse Current Test

With no input power applied, a 32.0 ± 0.1 volts DC source shall be applied to the charger output terminals of common polarity for a period of one hour. The charger shall sustain no damage, and the reverse current shall not exceed 10 milliamperes.

NOTE

FOR ACCEPTANCE TESTS, THE TIME PERIOD MAY BE SHORTENED AS NECESSARY TO REDUCE OVERALL TEST TIME.

4.6.1.2.12 Open Circuit Test

The charger shall be operated into an open circuit, with maximum input voltage applied, for a period of one hour. The charger shall sustain no damage.

NOTE

FOR ACCEPTANCE TESTS, THE TIME PERIOD MAY BE SHORTENED AS NECESSARY TO REDUCE OVERALL TEST TIME.

4.6.1.2.13 Charger Disable

The fault conditions specified in Paragraph 3.2.1.2.8 shall be simulated while the charger is operating. Each fault condition shall cause the charger output to disable. Upon correction of the imposed fault condition, the charger shall automatically return to normal operation.

4.6.1.2.14 Software Verification

The software developed per Paragraph 3.3.1.2.1 shall be verified using the applicable evaluation criteria specified in MIL-STD-2167.

4.6.1.3 System

Unless otherwise specified, the system tests shall be performed with the charger connected to the battery and operated in all applicable charging modes.

4.6.1.3.1 Normal AC Input

The system shall be operated over the full range of normal input voltage and frequency as defined by Table I of MIL-STD-704. The charger shall remain stable under all conditions and the output shall remain within specified limits.

4.6.1.3.2 Abnormal AC Input

The system shall be operated under all combinations of overvoltage, undervoltage, overfrequency, and underfrequency limits as defined by Figures 6 and 7 of MIL-STD-704. The charger shall remain stable, but degraded performance is allowable.

4.6.1.3.3 Input Voltage Spikes

The system shall be operated using standard input conditions and a voltage spike shall be superimposed with a spike generator having an effective internal impedance of $50 \pm 5\Omega$. The open circuit spike voltage waveform shall conform with MIL-STD-461, except that the spike voltage shall not exceed ± 200 volts. One hundred spikes of each polarity shall be applied within a period of one minute. The charger shall remain stable and shall sustain no damage.

4.6.1.3.4 Phase Power Loss

The system shall be operated under all combinations of phase power loss, including initial application of 1-phase and 2-phase power, and removal of each phase one at a time and two at a time. Each condition shall be maintained until stable operation has been reached. The charger shall sustain no damage and shall not cause an unsafe condition.

4.6.1.3.5 Charge Time

The system shall be operated in accordance with the conditions of Table III. When required by the detail specification sheet, a separate load current shall be applied during the charge period. After charging for the specified time at each condition, the battery shall be discharged to verify conformance with the specified capacity requirement.

4.6.1.3.6 Charge Regulation

The system shall be operated in accordance with the conditions of Table III. After charging to the 100 percent level for the specified charge time, the input power to the charger shall be removed

and the battery shall be discharged to remove 20 percent of rated capacity. Upon reapplication of input power, the charger shall initiate a new charge cycle and return the battery to the 100 percent capacity level. The battery then shall be discharged and shall deliver no less than rated capacity.

4.6.1.3.7 Operating Position

The system shall be operated using standard input conditions and the battery and charger shall be rotated in 90 degree increments so that each orthogonal surface faces upwards. The minimum dwell time in each position shall be 5 minutes. The system shall remain stable under all conditions and the output shall remain within specified limits.

4.6.2 Environmental Tests

The system shall be subjected to the environmental tests specified herein. The battery and charger may be tested separately or together, but the same test conditions shall apply to both articles. For each test, the requirements of Paragraph 3.2.5, items (a) through (g) shall apply.

4.6.2.1 High Temperature

The system shall be tested in accordance with MIL-STD-810, Method 501.3, Procedure II.

4.6.2.2 Low Temperature

The system shall be tested in accordance with MIL-STD-810, Method 502.3, Procedure II.

4.6.2.3 Altitude

The system shall be tested in accordance with the MIL-STD-810, Method 500.3, Procedure II. Operation shall be at the maximum altitude and maximum temperature conditions specified in Paragraph 3.2.5.3.

4.6.2.4 Temperature Shock

The system shall be tested in accordance with MIL-STD-810, Method 503.3.

4.6.2.5 Vibration

The system shall be tested in accordance with MIL-STD-810, Method 514.4, Procedure I.

4.6.2.6 Mechanical Shock

The system shall be tested in accordance with MIL-STD-810, Method 516.4, Procedure I.

4.6.2.7 Acceleration

The system shall be tested in accordance with MIL-STD-810, Method 513.4, Procedure II. Engineering analysis per Paragraph 4.4 may be used in lieu of test results for satisfying this requirement.

4.6.2.8 Explosive Atmosphere

The system shall be tested in accordance with MIL-STD-810, Method 511.3, Procedure I. Engineering analysis per Paragraph 4.4 may be used in lieu of test results for satisfying this requirement.

4.6.2.9 Humidity

The system shall be tested in accordance with MIL-STD-810, Method 507.3, Procedure II.

4.6.2.10 Salt Fog

The system shall be tested in accordance with MIL-STD-810, Method 509.3, Procedure I.

4.6.2.11 Sand and Dust

The system shall be tested in accordance with MIL-STD-810, Method 510.3, Procedures I and II. Engineering analysis per Paragraph 4.4 may be used in lieu of test results for satisfying this requirement.

4.6.3 Reliability Test

A reliability development/growth test shall be performed in accordance with MIL-STD-785, Task 302. The system shall be operated for a minimum of 2000 hours.

5 **PREPARATION FOR DELIVERY**

5.1 **Preservation, Packaging and Packing**

Preservation, packaging and packing requirements shall be in accordance with the applicable requirements of MIL-P-6063 for the battery and MIL-STD-2073-1 for the charger.

5.2 **Marking for Shipment**

Interior packages and exterior shipping containers shall be marked in accordance with the requirements of MIL-STD-129.

6 NOTES

6.1 Intended Use

The system covered by this specification is intended for use in a broad spectrum of Air Force aircraft applications.

6.2 Specification Format

This specification was prepared in accordance with MIL-STD-490, Appendix II.

6.3 Detail Specification Sheets

The detail specification sheet for each target aircraft application shall specify the following requirements, as a minimum.

a. Connector pin assignments (3.1.2)
b. Battery capacity rating (3.2.1.1.2)
c. Charger output rating (3.2.1.2.2)
d. Charge regulation parameters (3.2.1.2.4)
e. Load current requirements, if applicable (3.2.1.2.5)
f. Output signal characteristics (3.2.1.2.6 and 3.2.1.2.7)
g. Maximum weight of battery and charger (3.2.2.1)
h. Outline dimensions of battery and charger (3.2.2.2)
i. Mounting provisions for battery and charger (3.2.2.3)
j. Number of cells per battery (3.3.1.1.1)
k. Temperature sensor characteristics (3.3.1.1.5)
l. Current sensor characteristics (3.3.1.1.6)
m. Battery heater requirements, as applicable (3.3.1.1.7)
n. Battery thermal switch set point (3.3.1.1.8)
o. Battery receptacles (3.3.1.1.10)
p. Charger receptacles (3.3.1.2.4).

APPENDIX B
BC2000/01 PRIME ITEM DEVELOPMENT SPECIFICATION
(21 PAGES)

CRANE ELDEC CORPORATION

A SUBSIDIARY OF CRANE CO.

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Doc. No.:	BC2000/01	Rev.:	–
Title:	PRIME ITEM DEVELOPMENT SPECIFICATION ADVANCED MAINTENANCE-FREE AIRCRAFT BATTERY SYSTEM - DETAIL SPECIFICATION		
ELDEC P/N:	8-774-01		
Customer P/N:			
Data Item No.:			

REV.	PARA.	CHANGE RECORD
		This document is computer-controlled by EPIC (ELDEC Product Information Control). EPIC approval names for the current revision are listed at the bottom of the Title page. Approval names and dates for previous revisions are listed on the Change Record Pages. Revised or added text is indicated by a vertical line (revision bar) in the right-hand margin extending close to the entire area of the material affected. Relocation of material to another page is indicated by a revision bar opposite the REV. block, located in the lower right-hand corner of the page onto which the material is moved.
–		Initial issue.

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CR-1	–										
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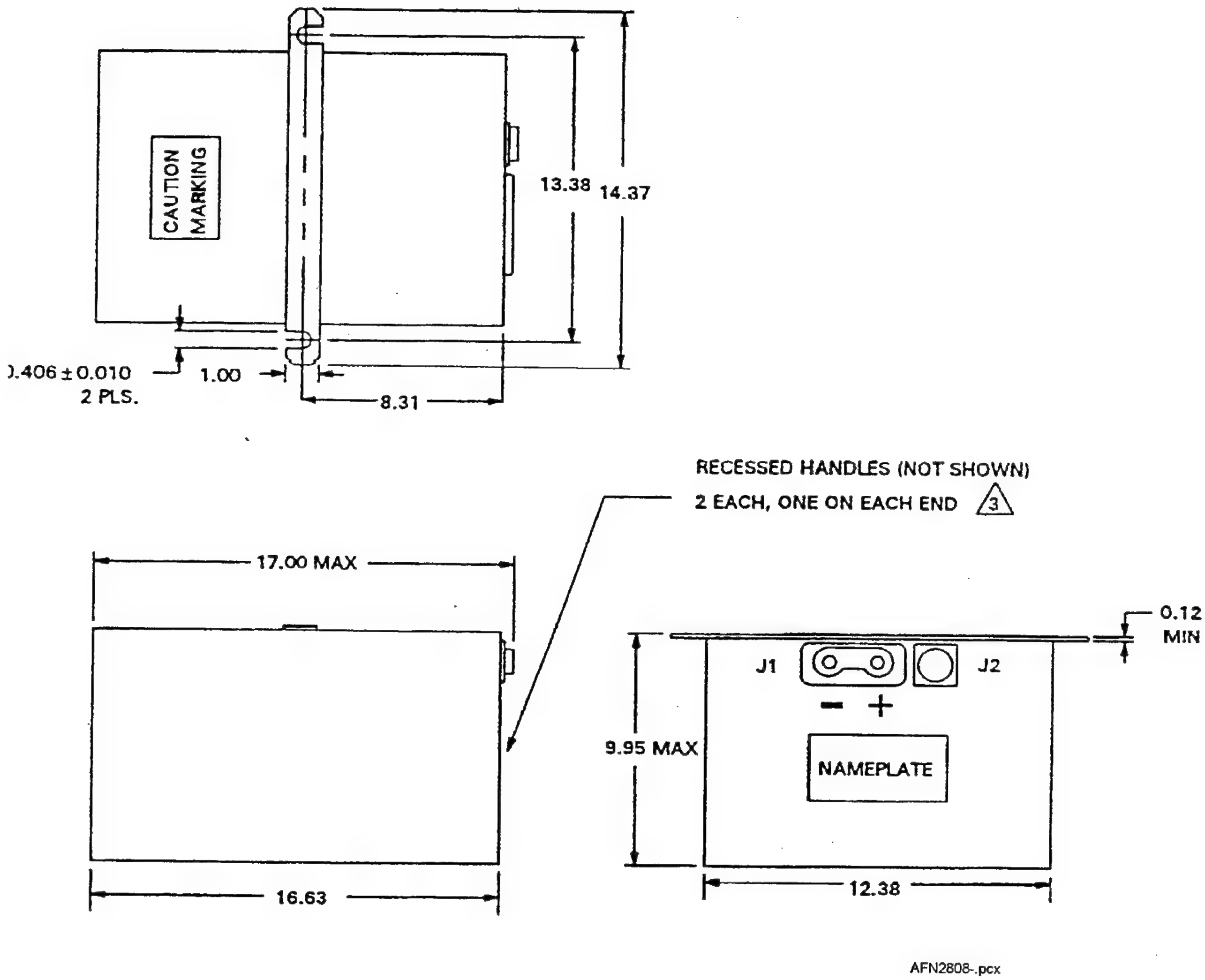
1. REQUIREMENTS:

1. The system shall consist of:

Battery Part Number:	Eagle-Picher P/N 18233
Charger Part Number:	ELDEC P/N 8-774-01
Display Panel Part Number:	Not applicable (This item to be supplied by aircraft vendor)

2. Battery capacity rating: 40 ampere-hours (end-of-life)
3. Battery maximum weight: 95 pounds
4. Battery dimensions and mounting provisions: see Figure 1
5. Number of cells per battery: 20
6. Temperature sensor: Analog Devices AD590 or equivalent
7. Current Sensor: Dynamic range 20 mA to 300 A, bi-directional, ± 1% accuracy
8. Battery heater rating: Not applicable
9. Battery thermal switch setpoint: 80 ± 5 °C
10. Battery receptacle definition:

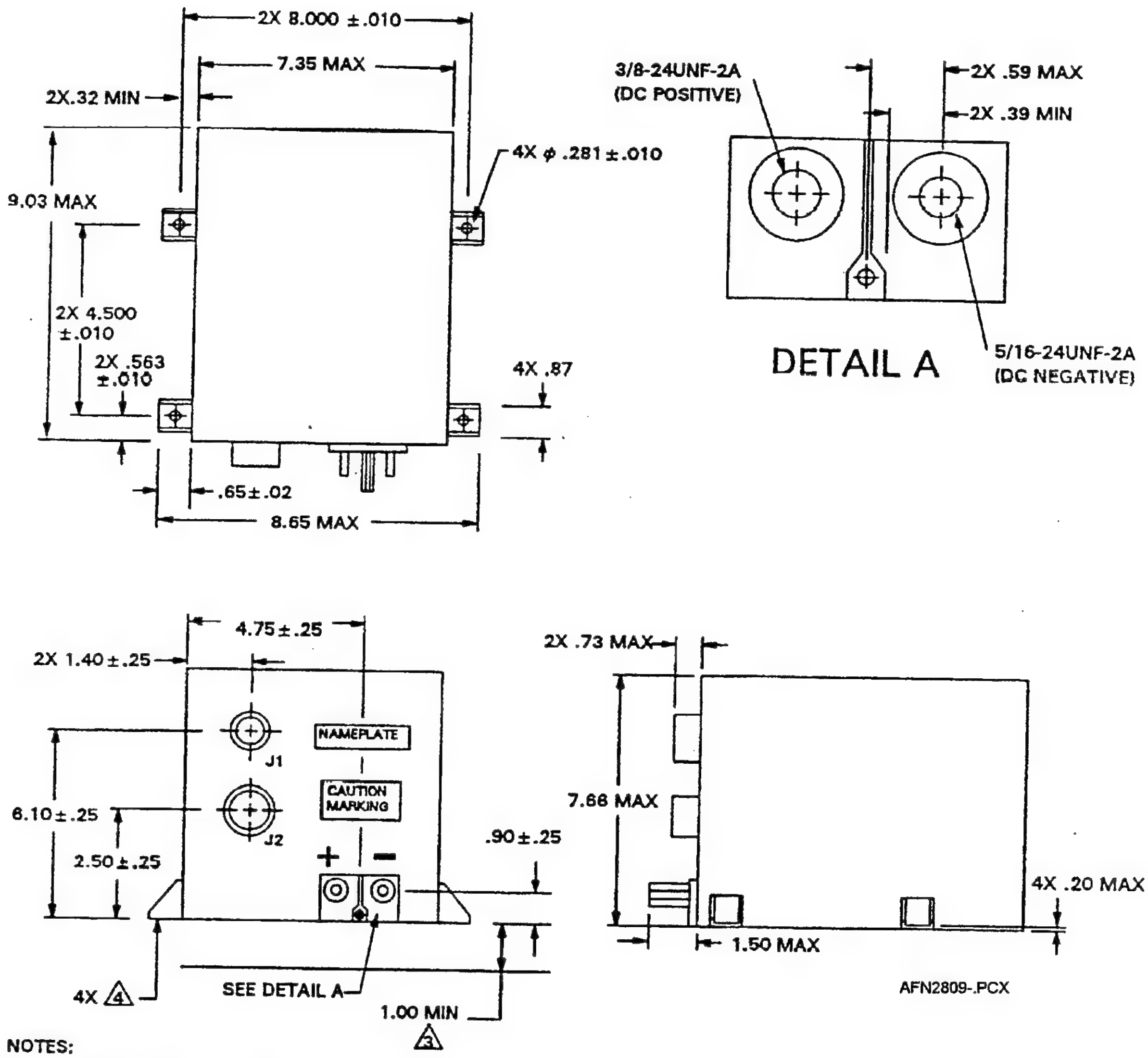
    J1 = MS3509
    J2 = MS27505E17B99P
11. Charger input rating: 115 VAC, 3-phase, 400 Hz, 5 amperes max. per phase
12. Charger output rating: 40 amperes continuous, 32 VDC max.
13. Charger maximum weight: 18 pounds
14. Charger dimensions and mounting provisions: see Figure 2



NOTES:

1. DIMENSIONS ARE IN INCHES.
2. TOLERANCES ARE 0.03 INCH EXCEPT AS SHOWN.
3. HANDLES SHALL NOT PROTRUDE BEYOND OUTLINE DIMENSION WHEN NOT IN USE.

Figure 1
Battery Envelope



NOTES:

1. ALL DIMENSIONS ARE IN INCHES.
2. TOLERANCES ARE 0.02 INCH EXCEPT AS SHOWN.
3. INSTALLATION SHALL PROVIDE MINIMUM OF 1" GAP BELOW UNIT TO ALLOW FREE CONVECTION AIRFLOW UPWARD THROUGH INTERNAL HEATSINKS.
4. PAINT-FREE SURFACE FOR ELECTRICAL BONDING.
5. J1 = MS27505E15B97P
   J2 = MS27505E19B32P

Figure 2
Charger Envelope

15. Charge regulation parameters:

    Charge initiation - On AC power-up and if battery state-of-charge drops below 80 percent
    Charge termination - On AC power-down or when battery reaches full charge

16. Charger receptacle definition:

    Positive terminal stud = 3/8-24UNF-2A
    Negative terminal stud = 5/16-24UNF-2A
    J1 = MS27505E15B97P
    J2 = MS27505E19B32P

17. Display panel definition: see Figure 3
18. Wiring diagram and connector pin assignments: see Figure 4
19. Vibration test levels: see Figure 5
20. Battery high rate performance: see Table 2
21. Maximum charge time: see Table 3
22. The system shall comply with the requirements of BC-2000B except as modified by the Following.

    2.1 Government documents. Replace MIL-STD-704E with MIL-STD-704D, MIL-STD-810E with MIL-STD-810C, and MIL-STD-461C with MIL-STD-461A.

    3.2.5.1 Temperature. Change "Class 2" to "Class 1".

    3.2.5.2 Altitude. Change "Class 2" to "Class 1".

    3.2.5.3 Temperature-altitude combination. Change "Class 2" to "Class 1".

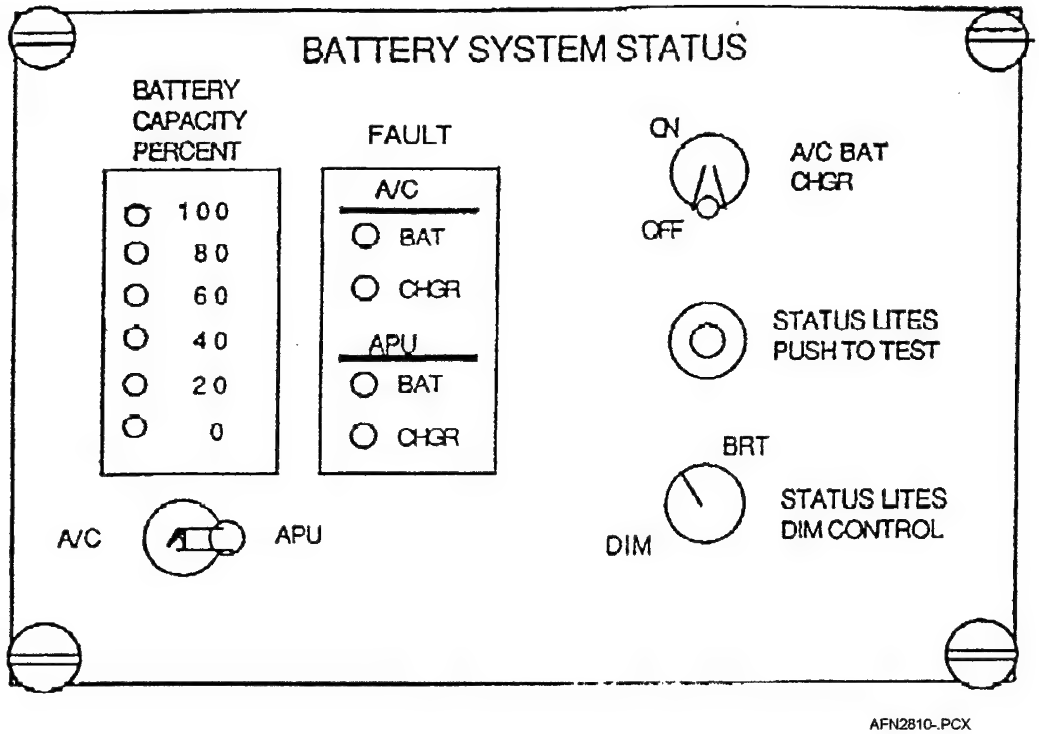
    3.2.5.4 Temperature shock. Change "Class 2" to "Class 1".

    3.2.5.5 Vibration. Replace with the following paragraph.

    The system shall be designed to withstand the random vibration environment as specified in Method 514.2 of MIL-STD-810, Procedure IA, except as modified below:

    a) Operating: Withstand vibration for 1 hour in three mutually perpendicular axes at the operating test levels shown in Figure 5.

    b) Non-Operating: Withstand vibration for 1 hour in three mutually perpendicular axes at the non-operating test levels shown in Figure 5.



NOTES:

1. Capacity LEDs shall turn on within ± 10 percent of indicated state-of-charge.

2. All LEDs shall illuminate momentarily when push-to-test is pressed. Battery state-of-charge and system fault status shall then be displayed for one minute with A/C power off, or continuously with A/C power on.

3. Panel dimensions and mounting provisions shall comply with MS25212.

4. Electrical interface to charger shall be per RS232 voltage levels and timing sequence, utilizing a full-duplex synchronous serial interface. Data bits are defined below:
   1)BAT_FAULT, 2)CHGR_FAULT, 3)BAT_SOC_100,
   4)BAT_SOC_80, 5)BAT_SOC_60, 6)BAT_SOC_40,
   7)BAT_SOC_20, 8)BAT_SOC_0, 9)DPU_LO_PWR.

Figure 3
Display Panel Interface

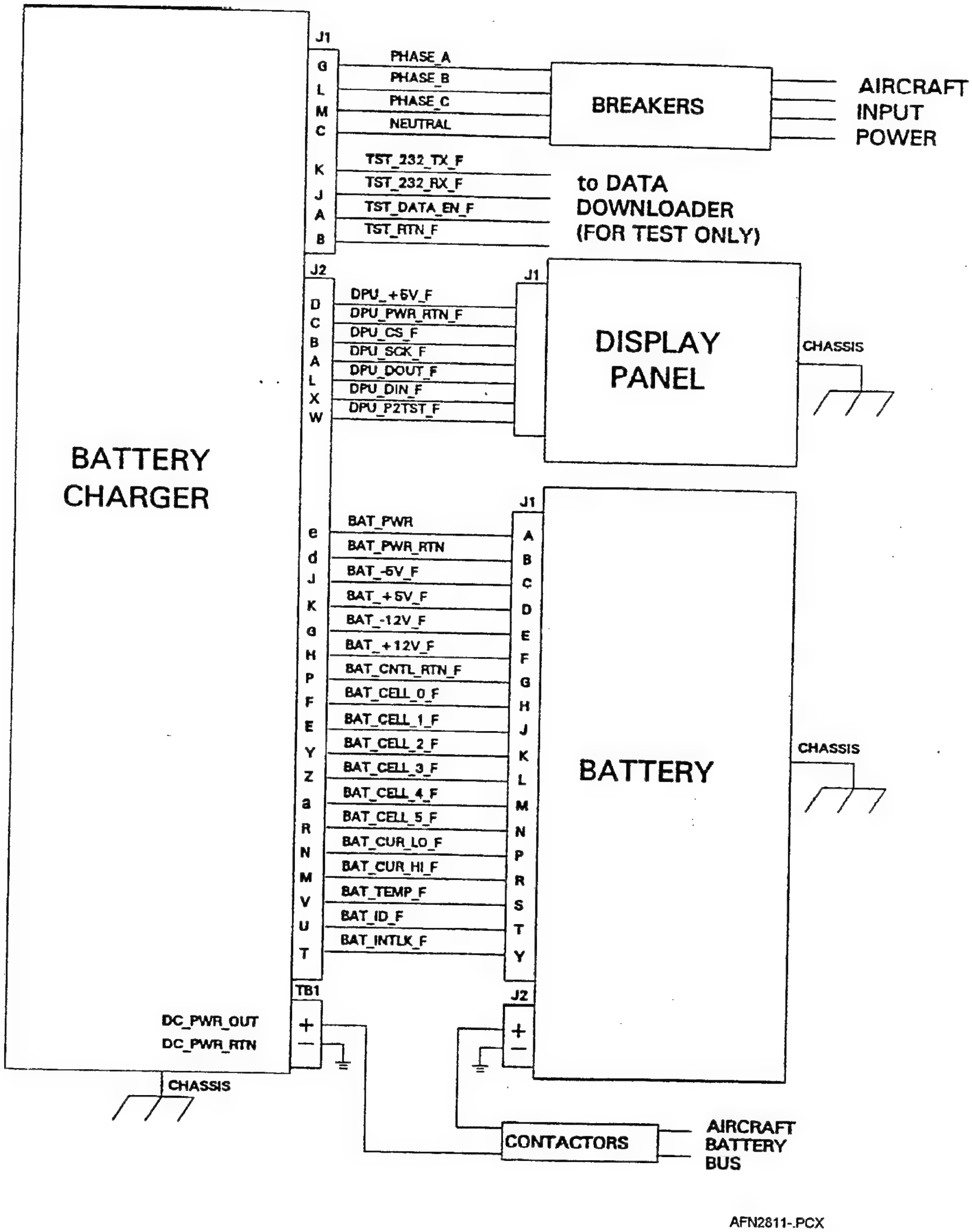
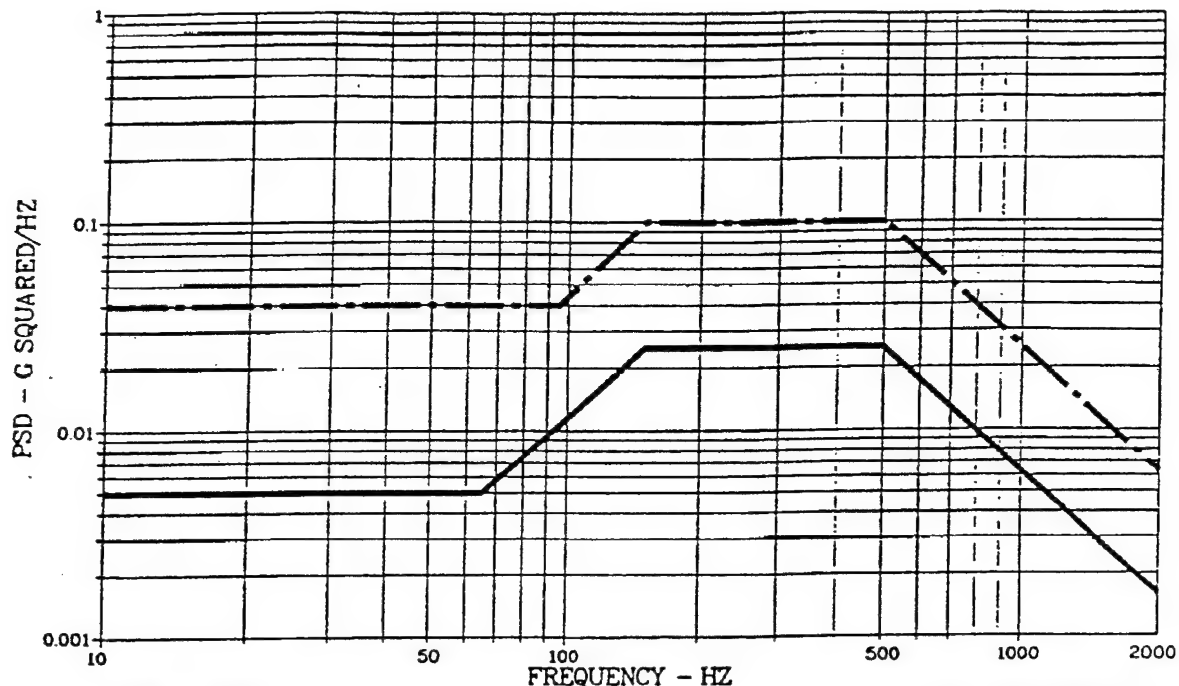


Figure 4
Wiring Diagram and Connector Pin Assignments



OPERATING

NON - OPERATING

TEST SEQUENCE PER AXIS:
1/2 HR OPERATING
1 HR NON-OPERATING
1/2 HR OPERATING

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OPERATING LEVELS

FREQ HZ	PSD G SQD/HZ	FREQ HZ	PSD G SQD/HZ	SLOPE DB/OCT	G SQD
10.0	0.0050	65.0	0.0050	0.0	0.27
65.0	0.0050	150.0	0.0250	5.8	1.17
150.0	0.0250	500.0	0.0250	0.0	8.75
500.0	0.0250	2000.0	0.0016	-6.0	9.46
TOTAL G SQD EQUALS					19.66
OVERALL G RMS EQUALS					4.43

NON-OPERATING LEVELS

FREQ HZ	PSD G SQD/HZ	FREQ HZ	PSD G SQD/HZ	SLOPE DB/OCT	G SQD
10.0	0.0400	95.0	0.0400	0.0	3.40
95.0	0.0400	150.0	0.1000	6.0	3.73
150.0	0.1000	500.0	0.1000	0.0	35.00
500.0	0.1000	2000.0	0.0063	-6.0	37.62
TOTAL G SQD EQUALS					79.74
OVERALL G RMS EQUALS					8.93

Figure 5
Vibration Test Levels

Table 1
Battery Discharge Requirements

(see BC-2000B)

Table 2
Battery High Rate Requirements

(Replace Table II of BC-2000B with the following table)

MINIMUM CURRENT VERSUS TIME FOR

CONSTANT 12.0-VOLT DISCHARGE

Time in Seconds	Current in Amperes	
	At 25°C	AT -18°C
0^+	1725	1275
15	1375	975
30	1050	750
45	800	550
60	600	400

Table 3
Minimum Charge Time

(Replace Table III of BC-2000B with the following table)

Temperature (°C)	To 80 % of 1C Capacity (hours)	To 100% of 1C Capacity (hours)
49	2.0	3.0
25	1.0	2.0
-18	3.0	5.0
-40	4.0	6.0

c) Shipping Vibration: When packaged for shipping, the equipment shall withstand the vibration specified below:

FREQUENCY	**AMPLITUDE**
5 to 27 Hz	± 1.3 G peak
27 to 51 Hz	0.036 inches double amplitude
51 to 500 Hz	± 5 G peak

Sweep rate: 1 octave per minute
Duration 1.5 hours in each of three axes

3.2.5.6 Mechanical Shock Replace with the following paragraphs.

3.2.5.6.1 Operational shock. The system shall be designed to withstand the operational shock as specified in Method 516.2 of MIL-STD-810, Procedure I.

3.2.5.6.2 Non-operational shock. The system installed in its shipping case shall be designed to withstand the non-operational shock as specified in Method 516.2 of MIL-STD-810, Procedure II.

3.2.5.6.3 Bench handling shock. The system shall be designed to withstand the bench handling servicing shock environment as specified in Method 516.2 of MIL-STD-810, Procedure V.

3.2.5.13 Decompression. (New Paragraph)

The system shall withstand exposure to sudden decompression of the surrounding ambient air. The conditions shall consist of a pressure decrease from 11.0 psia to 2.5 psia within 5.0 seconds then a gradual increase to 5.5 psia in 5 minutes.

3.3.2 Electromagnetic radiation. Replace with the following paragraphs:

3.3.2.1 Electromagnetic Interference. The system shall meet the requirements of MIL-STD-461A, Notice 3, as modified below, and shall be tested in accordance with MIL-STD-462, Notice 2.

CE03 [a]	CS01 [c]	RE02 [a,e]	RS02 [f]
CE04 [a, b]	CS02 [d]		RS03 [g]
	CS06		RS100 [f]

Note: Letters in brackets correspond to subparagraphs below.

a. Transient interference emission occurring at the instant of operations while cycling power ON/OFF to the test sample shall be relaxed by 20 dB above the broadband limit.

b. Applies to signal cables and all bundles, both shielded and unshielded.

c. Applies to DC power leads only.

d. Applies to AC and DC leads. Test over a frequency range of 14 kHz to 400 MHz.

e. Method RE02 shall cover the frequency range of 14 kHz to 20 GHz. The broadband limits shall be as specified in the military standard over the 14 kHz to 1.0 GHz frequency range and shall be constant 80 dB mV/m/MHz over the 1.0 to 20 GHz frequency range. The narrow band limit shall be per MIL-STD-461 over the 14 kHz to 10 GHz frequency range and shall be a constant 70 dB mV/m over the 10 to 20 GHz frequency range.

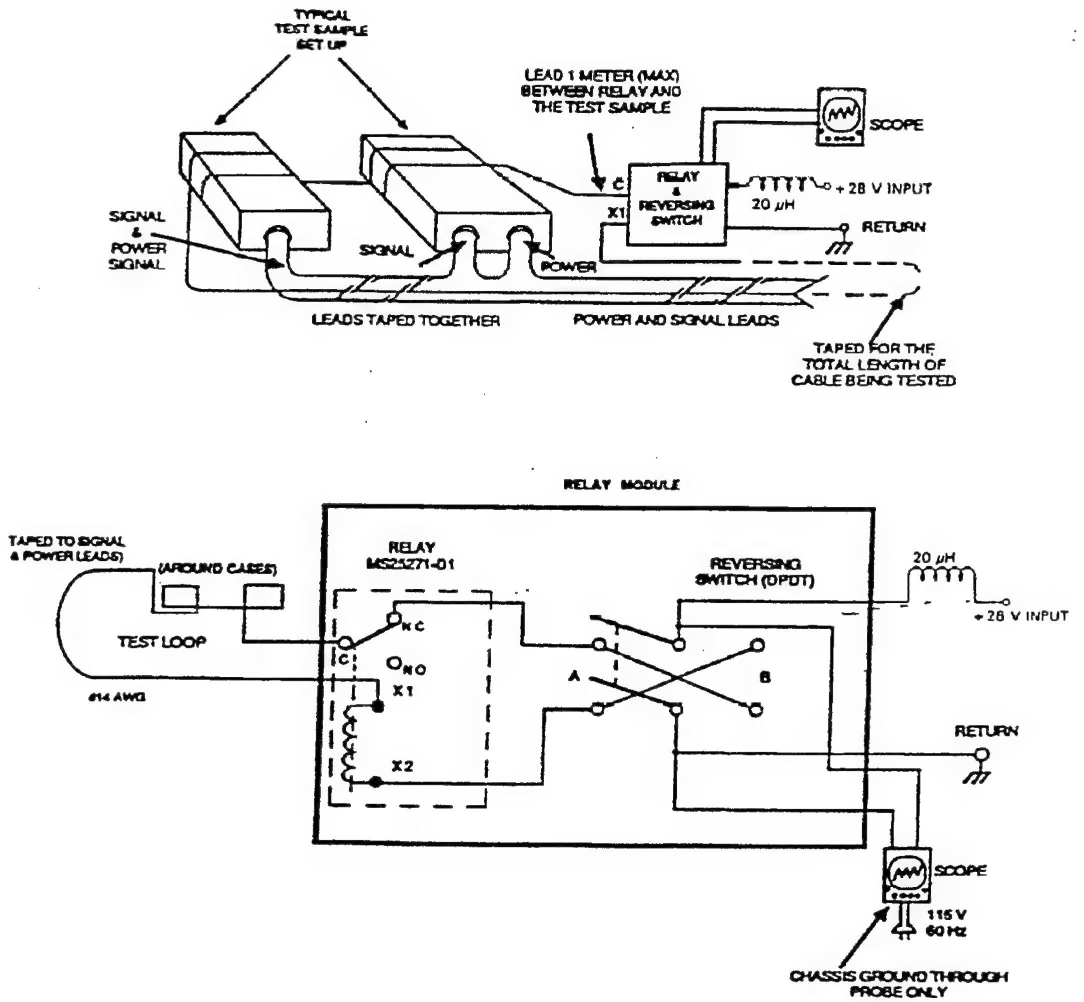
f. In addition to the Power Frequency Test and the Spike Test required by MIL-STD-461, Method RS02 shall also be performed using as the test signal source an MS25271 or equivalent relay, connected so as to form a "chattering relay". A switch shall be included to reverse the polarity of the relay spikes during the test. Refer to 3.3.2.2 and Figure 1 herein for the test setup.

g. The RS03 requirement is applicable over the 0.014 MHz to 20 GHz frequency range using the field intensities and modulations specified in Table 4.

Table 4
Field Intensity and Modulation Requirements RS03

Frequency Range	Field Intensity	Modulation Characteristics
0.01 to 29.9 MHz	20 volts/meter	AM, 50%, 1000 Hz tone
30 to 75.9 MHz	20 volts/meter	FM, ± 8 kHz deviation 1000 Hz tone
76 to 399.9 MHz	20 volts/meter	AM, 50%, 1000 Hz tone
400 to 1.999 GHz	20 volts/meter	Pulse, 1.0 μsec pulse width, 400 pps
2.0 to 20 GHz	20 volts/meter	Pulse, 01 μsec pulse width, 400 pps

3.3.2.2 RS100 Transient Susceptibility Requirements. The flight avionics shall meet the following requirements in addition to RS02. No change in indication, malfunction, or degradation of performance as specified in this document shall be produced when all cables and cases are exposed to transient fields. The transient fields shall be generated by a MS25271 relay or equivalent, wired for continuous operation and radiated by a No. 14 AWG wire as shown in Figure 6. No suppression or modification shall be attached to the relay or its wiring. The tests shall be conducted for a period commensurate with equipment operation but no less than five minutes for each switch position. A scope shall be connected into the circuit as shown in Figure 6 to read the transient voltage continuously during the test period. The transient peak reading shall be 200 volts or more. Remove the 10 mfd feed-thru capacitor (required for the CE tests) from the 28 volt power lines when performing this test.



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NOTES:

1. All wiring shall be 5 cm ± 1 cm above ground plane.

2. Feed through capacitors (10 microfarads each, required for the CE tests) shall be removed from the +28 VDC power leads and add a 20 μH choke in series with the switch and the +28 VDC Bus.

3. +28 VDC to the relay shall be obtained from the +28 VDC to test sample where the feed-through capacitor was in line.

4. Test loop is taped to signal and power leads around cases.

Figure 6
RS100 Transient Induced Susceptibility Test

3.3.2.3 Bonds and Grounds. The system shall be electrically bonded in accordance with MIL-B-5087, Paragraph 3.3.3 (Class H shock hazard) and Paragraph 3.3.5 (Class R RF potentials). MIL-STD-1857 shall be used as a design guide. Bonding for new or relocated equipment current path returns, RF potentials, and shock hazards shall be so installed that expansion, contraction, or movement incident to normal service use and transportation shall not break or loosen the connection. Surface preparation for bonds and grounds shall be accomplished by removing all anodic film, grease, paint, lacquer, or other high resistance properties from the immediate area of contact. The electrical bonding resistance between equipment chassis, including the mounting rack or plate, and the aircraft structure shall not exceed 2.5 milliohms.

3.3.2.4 Cables and Connectors. Modification-related case-and chassis-mounted connectors shall have an approved, RF conductive finish. Bonding impedance of the connector shell to the case or chassis shall not exceed 2.5 milliohms. Coaxial cable shall be of the double shielded type. Other cables requiring overall shields shall have a tinned copper braid shield providing an attenuation of at least 60 dB to electric and magnetic fields or provide sufficient attenuation to meet the radiated emission and susceptibility requirements of MIL-STD-461, Notice 3 as modified by 3.3.2.1 and 3.3.2.5 herein. Connectors used with cables requiring an overall shield shall have an approved RF conductive finish and be provided with EMI backshells for 360° peripheral bonding of the cable shield.

3.3.2.5 Shield Grounding. Grounding of shields shall comply with 3.12 of MIL-W-5088.

4.6.1.2.4 Electromagnetic compatibility. Replace with the following paragraph.

The system shall be tested in accordance with MIL-STD-462, Notice 2 to verify that the electromagnetic emission and susceptibility requirements of Paragraphs 3.3.2.1 through 3.3.2.5 herein have been satisfied. Flight approval shall be permitted only after meeting selected requirements from MIL-STD-461, Notice 3. These selected requirements are CE03, RE02, RS03, and RS100.

4.6.1.3.5 Charge time. For each temperature condition, the test shall be conducted as follows:

a. Stabilize fully charged battery at test temperature.

b. Discharge battery at the 1C rate (40 amperes) to 18.0 volts.

c. Again stabilize battery at test temperature.

d. Expose battery to 25 ± 3°C ambient temperature and immediately begin charging.

e. Maintain ambient temperature at 25 ± 3°C for the entire charge period.

f. After charging for the specified time period, discharge battery per step (b) to verify conformance with the specified capacity requirement.

4.6.2.1 High temperature. Replace Method 501.3 with Method 501.1.

4.6.2.2 Low temperature. Replace Method 502.3 with 502.1.

4.6.2.3 Altitude. Replace with the following paragraph.

4.6.2.3 Temperature - Altitude. The equipment shall be subjected to the test of Method 504.1, Procedure I of MIL-STD-810. The test shall be in accordance with test Category 5 except of the following modifications:

Modified Step	Temperature (°C)	Altitude (Ft)
1b	-54	site
3	-54	42,000
6	+68	site
10	+45	25,000
11	+61	25,000
12	+29.4	42,000
13	+45	42,000

4.6.2.4 Temperature Shock. Replace with the following paragraph.

The system shall be subjected to the test of Method 511.1, Procedure I of MIL-STD-810, except the high temperature shall be 85°C.

4.6.2.5 Vibration. Replace with the following paragraph.

The system shall be tested in accordance with the random vibration environment as specified in Method 514.2 of MIL-STD-810, Procedure IA, except as modified below:

a) Operating: The system shall operate within specified performance without mechanical damage while being vibrated for 1 hour in each of three mutually perpendicular axes at the test levels shown in Figure 5.

b) Non-Operating: The system shall be vibration tested for 1 hour in each of three mutually perpendicular axes at the non-operating test levels shown in Figure 5. The equipment shall incur no mechanical damage and shall meet specified performance before and after non-operating vibration exposure.

The test shall consist of 0.5 hour at operating test levels, followed by 1.0 hour at non-operating test levels, followed by 0.5 hour at operating test levels.

4.6.2.6 Mechanical shock. Replace with the following paragraphs.

4.6.2.6.1 Operational shock. The system shall be tested in accordance with operational shock requirements as specified in Method 516.2 of MIL-STD-810, Procedure I. The equipment shall be energized during this test. The equipment shall meet specified performance and shall incur no mechanical damage as a result of this test.

4.6.2.6.2 Bench handling shock. The system shall be tested in accordance with the shock requirements as specified in Method 516.2 of MIL-STD-810, Procedure V. The equipment shall meet specified performance and shall incur no mechanical damage as a result of this test.

4.6.2.7 Acceleration. Replace Method 513.4 with Method 513.2.

4.6.2.8 Explosive atmosphere. Replace with the following paragraph.

The system shall be subjected to the test of Method 511.1, Procedure I of MIL-STD-810. Maximum simulated test altitude shall be 42,000 feet.

4.6.2.9 Humidity. Replace with the following paragraph.

The system shall be subjected to the test of Method 507.1, Procedure II or III of MIL-STD-810, depending upon design of the equipment. Procedure III shall be used for equipment or components which contain areas normally sealed during operation by gasket or other non-hermetic type seal. In Step 6 of both procedures, the equipment shall operate within specified performance during the last 5 hours of the last cycle.

4.6.2.10 Salt fog. Replace with the following paragraph.

The system shall be subjected to the test of Method 509.1, Procedure I of MIL-STD-810. Failure criteria shall be limited to the following:

a. Items having movable mating parts such as exposed bearing assemblies shall be rotated or otherwise moved through their full range of movement or adjustment without binding or the use of other than normal force.

b. Corrosion shall not be evident on metals or finished surfaces. Corrosion shall mean any visible degradation such as flaked, pitted, blistered, delaminated, or otherwise loosened finish or metal surfaces.

4.6.2.11 Sand and dust. Replace with the following paragraph.

The system shall be subjected to the test of Method 510.1, Procedure I of MIL-STD-810. The equipment shall be re-oriented periodically in Step 1 to expose all sides of the equipment equally. Equipment shall operate before Step 1 and during Step 5. Step 3 shall proceed immediately after stabilization in Step 2.

4.6.2.12 Fungus. (New Paragraph)

Fungus resistance tests shall be required only on those parts, subassemblies, or assemblies which use fungus nutrient materials in their construction. The test shall be performed in accordance with Method 508.1, Procedure I of MIL-STD-810. If no fungus nutrient materials are used, a certification to that effect shall be provided by the seller.

4.6.2.13 Ambient Air Pressure (New Paragraph)

The system shall be subjected to a test simulating sudden decompression. The external pressure shall be lowered from 11.0 psia to 2.5 psia within 5.0 seconds then gradually raised to 5.5 psia in 5 minutes. Prior to, during, and at the conclusion of this test, the equipment's specified performance shall be verified and the equipment inspected for mechanical damage.

APPENDIX C
EPI CONFERENCE PAPER
LIFE CYCLE TESTING OF A SEALED 24-V, 42-AH NICKEL-CADMIUM AIRCRAFT BATTERY
(7 PAGES)

971216

Life Cycle Testing of a Sealed 24-V, 42-Ah Nickel-Cadmium Aircraft Battery

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ABSTRACT

Extensive research has been conducted in the design and manufacture of very long life sealed maintenance free nickel-cadmium aircraft batteries. This study presents data on a 100% depth of discharge (DOD) life test performed on a nominal capacity 42-Ah battery. The purpose of this study is to validate design concepts, determine the life characteristics of the newly designed sealed Ni-Cd batteries, and develop baseline information on failure rates and mechanisms. The data from this experiment can be used to compare depth of discharge versus battery life with similar tests such as the lower DOD experiments performed on spacecraft batteries. This information is important in the ongoing development of long life batteries and in developing failure models for life prediction.

INTRODUCTION

The Power Systems Department of Eagle-Picher Industries' Technologies Division, under a research and development contract, the AMFABS program, sponsored by the battery electrochemistry section of Wright Laboratory, Wright-Patterson Air Force Base, Dayton Ohio, has developed and is testing a sealed nickel-cadmium aircraft battery with a design life of 20 years. The batteries are available in capacities ranging from 5 ampere-hours to over 85 ampere-hours and with nominal voltages of 12, 24, and 28 volts. They can be configured to accommodate any footprint. Life cycle research is being conducted on spacecraft sealed Ni-Cd cells at depths of discharge (DOD) between 15 to 50 percent DOD. These battery tests have run into the tens of thousands of cycles. Ongoing tests have accumulated over 26,000 cycles. Previous to this test, Eagle Picher has performed life cycle testing on sealed aircraft cells up to 20% DOD on 17 Ah cells. This paper represents the first work towards life cycle testing at 100% DOD on aircraft sealed Ni-Cd cells.

TEST ITEM DESCRIPTION

The unit under test is a nominal 24-volt, 42-Ah name-plate capacity sealed Ni-Cd battery. The battery is constructed of prismatic, starved electrolyte (recombinant) nickel-cadmium cells enclosed in nylon cell cases. The cells are sealed with nylon-to-nylon compression seals and are equipped with over pressure release valves that operate at pressures over 50 psi. The cell pack consists of 14 positive electrodes and 15 negative electrodes. The electrodes are constructed using a slurry sinter plaque and impregnated using the dual impregnation process for the positive electrodes and an electrochemical process for the negative electrodes. The porosities of the positive and negative electrodes are 80% and 81%, respectively. The positive electrodes were electrochemically impregnated to 1.4 g/cm^3 void followed by a chemical impregnation to 2.1 g/cm^3 void. Positive impregnation loading levels for this application are fairly high, in the normal range of loading levels of 1.4 g/cm^3 void to 2.2 g/cm^3 void. This allows for a high energy density battery but will likely decrease the number of cycles to failure. The negative electrodes were impregnated to 2.2 g/cm^3 void in an electrochemical process. Cell separator is non-woven polypropylene that has been impregnated with polybenzimadazole (PBI) for permanent wettability. Individual cell weight is 4.15 lb. Initial testing of the battery shows the actual capacity of the battery to be 55 Ah. The initial charge and discharge curves are shown in Figures 1 and 2. The original room temperature internal resistance is 0.00041 ohm per cell. Two cells in the battery are equipped with pressure transducers to allow cell pressures to be monitored over the life test. Also, battery temperature is monitored using a thermocouple inserted between two cells towards the end of the battery.

TEST DESCRIPTION

The battery was located in a temperature chamber set at 21 °C. A cycle regime of four cycles a

day was decided upon in order to allow the battery temperature to stabilize at a value near 25 °C. Spacecraft cell testing shows that this is a slightly higher temperature than the ideal temperature for life cycle testing of 15 °C. This temperature was chosen to give another data point in addition to the spacecraft cell testing. The charge regime consists of a 42-A charge (1C rate) which is terminated when 103% of the capacity removed during discharge is put back into the battery. The battery is then top charged at a 21-A rate (C/2 rate) until an extra 4% of the discharge capacity has been put back into the battery. The discharge consists of a 42-A discharge for 1 hour. The battery is allowed to rest for 50 minutes between charge and discharge, and also for 3 hours after the discharge. The battery's capacity and internal resistance were measured at the beginning of the test and at 200-cycle intervals to determine how they change over the life of the battery.

BATTERY PERFORMANCE

Initial testing of the battery shows a nominal capacity of 56.5 Ah when discharged at 42 A. Figures 1 and 2 show the initial charge and discharge curves of this capacity cycle.

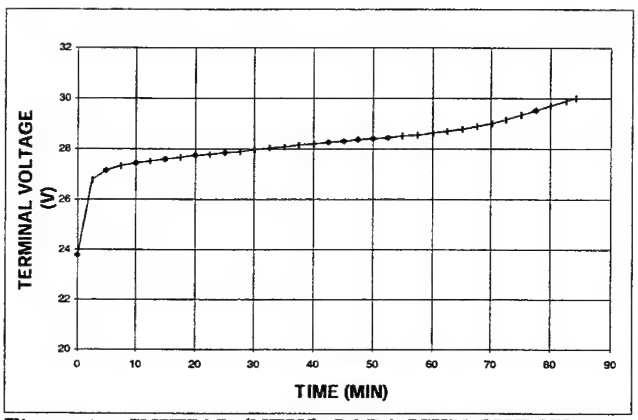

Figure 1. INITIAL (NEW) CAPACITY CHECK, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

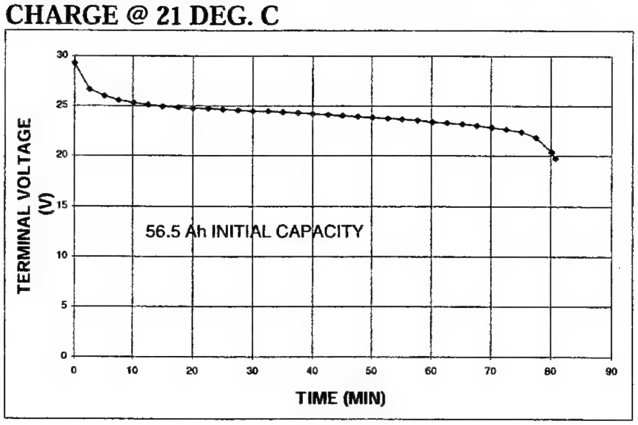

Figure 2. INITIAL (NEW) CAPACITY CHECK, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

The battery resistance is measured using two discharge rates and calculating resistance by $R = \frac{V_1 - V_2}{I_2 - I_1} = \frac{\Delta V}{\Delta I}$. Initial starting battery resistance was 0.0082 ohm when measured at current levels of $I_2 = 950$ A and $I_1 = 580$ A. See Figure 3. This parameter is important in applications that take advantage of the Ni-Cd battery's low internal resistance in powering high current draw equipment such as auxiliary power units. After completion of the capacity and internal resistance checks, the battery was started cycling.

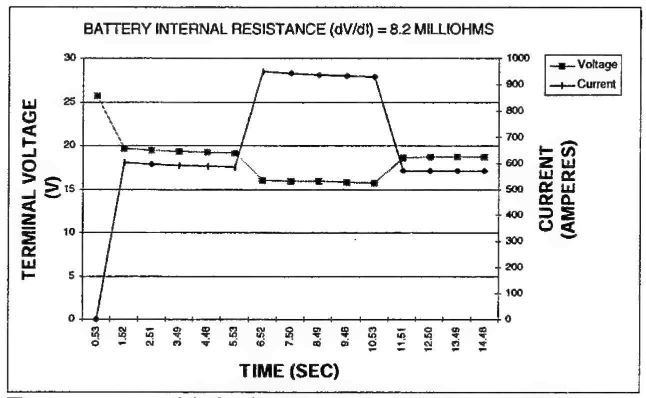

Figure 3. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C NEW BATTERY

At the 200 cycles mark, the battery cycling was halted as planned to measure battery performance, primarily the battery capacity and internal resistance. Figures 4 and 5 show the battery charge and discharge. As shown in Figure 5, the battery was allowed to discharge down to 1.0 volt per cell for the discharge voltage cutoff. Comparison of the original capacity to the 200 cycle mark capacity shows the battery has decreased in capacity by 1.5% to 55 Ah.

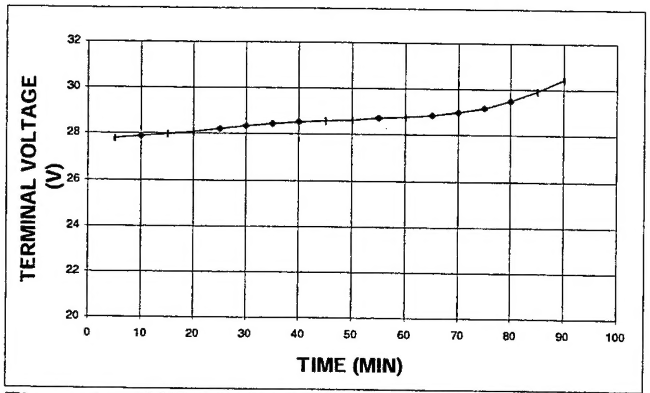

Figure 4. CAPACITY CHECK AFTER 200 CYCLES, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

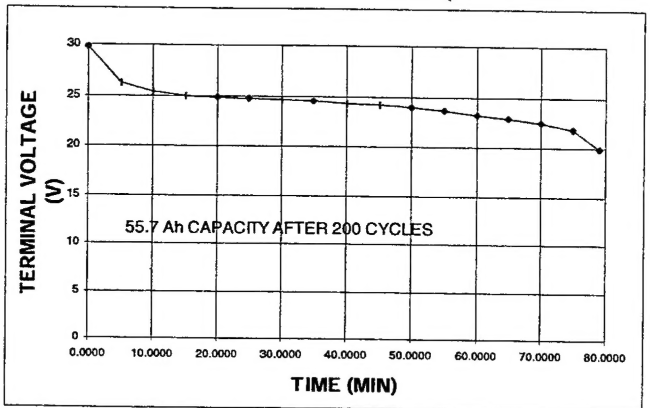

Figure 5. CAPACITY CHECK AFTER 200 CYCLES, 42 Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

The internal resistance of the battery increased by 0.0004 ohm or 4.7%. Figure 6 shows the internal resistance check after 200 cycles.

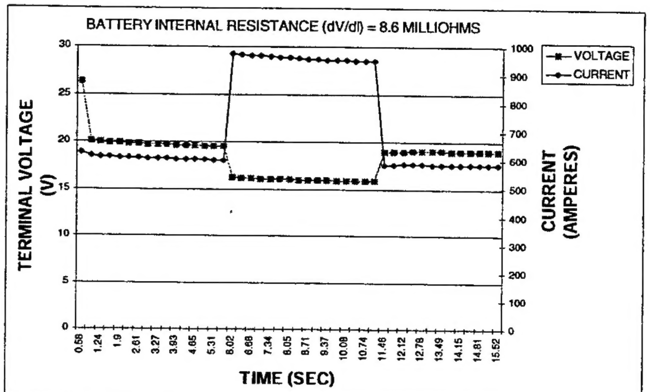

Figure 6. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C

After completion of the 200 cycle capacity and internal resistance checks, testing was resumed. The test was again stopped at cycle 400 for capacity and internal resistance checks. Figures 7 and 8 show the charge and discharge at the 400 cycle point. Figure 9 shows the internal resistance check. The battery capacity has decreased by 4% from the original capacity to 54.2 Ah. The internal resistance has increased by 3.5% from the original to 0.0085 ohm, but has gone down slightly from the measurements at 200 cycles.

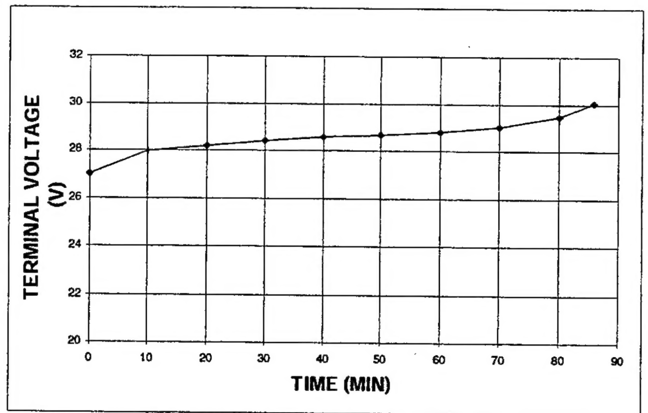

Figure 7. CAPACITY CHECK AFTER 400 CYCLES, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

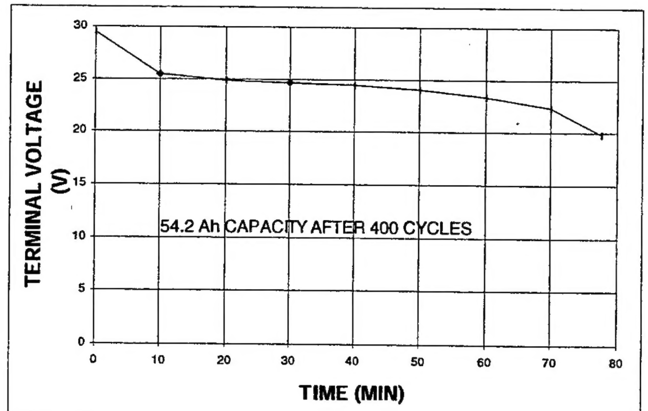

Figure 8. CAPACITY CHECK AFTER 400 CYCLES, 42 Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

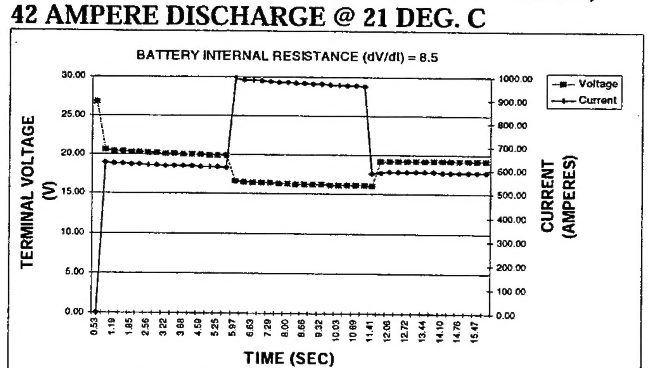

Figure 9. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C

AFTER 400 CYCLES

Upon completion of the characterization testing, cycling was resumed. The battery began to regularly hit the 31.0V cutoff voltage on charge around cycle 530. No changes were made at this time and the battery continued to cycled normally for 200 cycles. Cycling was halted at cycle number 600. Figures 10 and 11 show the charge and discharge at the 600 cycle point. Figure 12 shows the internal resistance check. The battery capacity has decreased by 10% from the original capacity to 51.1 Ah. The internal resistance has increased by 1% from the original to 0.0083 ohm.

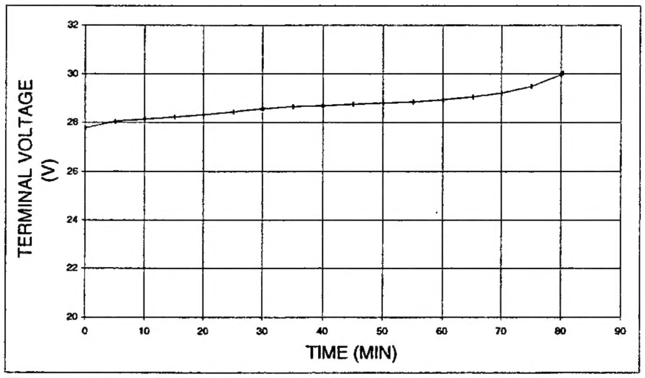

Figure 10. CAPACITY CHECK AFTER 600 CYCLES, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

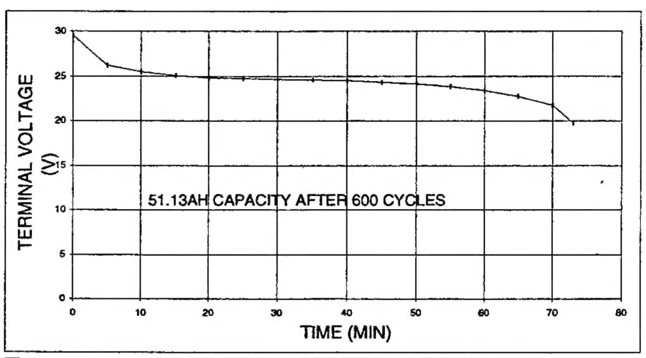

Figure 11. CAPACITY CHECK AFTER 600 CYCLES, 42 Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

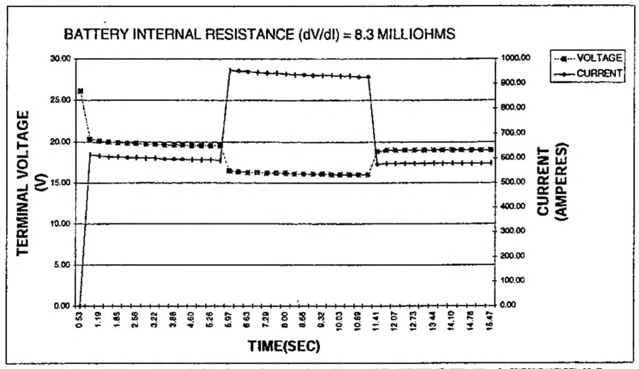

Figure 12. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C AFTER 600 CYCLES

Upon completion of the characterization testing, cycling was resumed. At cycle 680, the end of charge cutoff voltage was increased from 31.0V to 31.5V. The battery continued to cycle normally for 200 cycles and cycling was halted at number 800. Figures 13 and 14 show the charge and discharge at the 800 cycle point. Figure 15 shows the internal resistance check. The battery capacity has decreased by 3% from the original capacity to 54.8 Ah. The internal resistance has increased by 6% from the original to 0.0087 ohm.

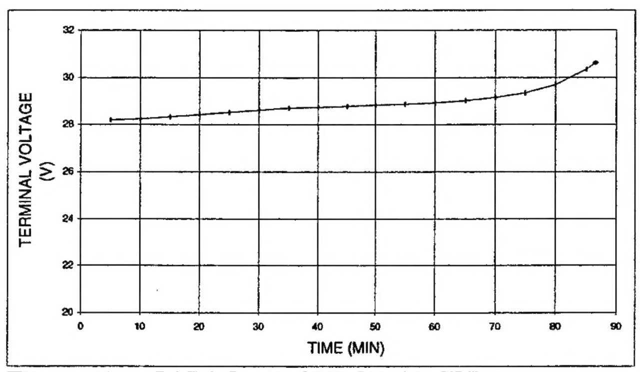

Figure 13. CAPACITY CHECK AFTER 800 CYCLES, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

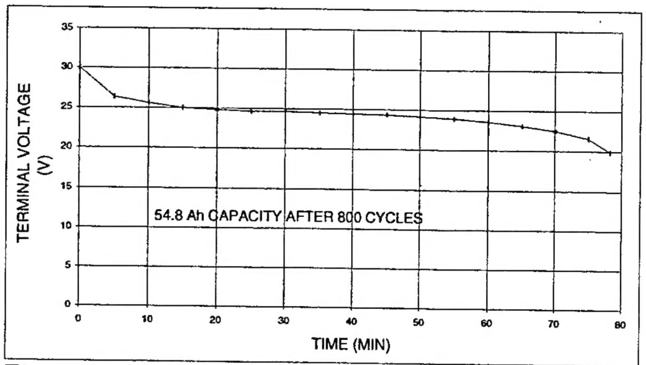

Figure 14. CAPACITY CHECK AFTER 800 CYCLES, 42 Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

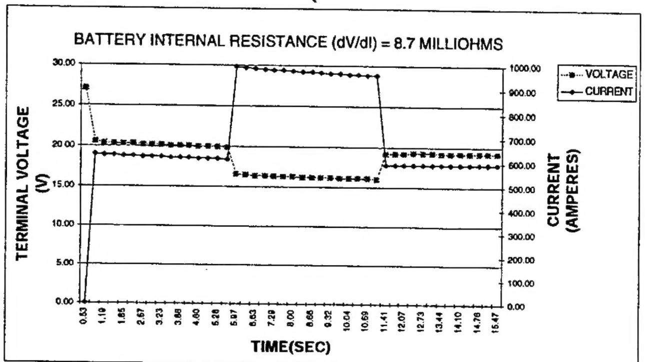

Figure 15. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C AFTER 800 CYCLES

Upon completion of the characterization testing, cycling was resumed. The battery cycled normally for 200 cycles and cycling was halted at number 1000. Figures 16 and 17 show the charge and discharge at the 1000 cycle point. Figure 18 shows the internal resistance check. The battery capacity has decreased by 1% from the original capacity to 55.7 Ah. The internal resistance has increased by 4% from the original to 0.0085 ohm.

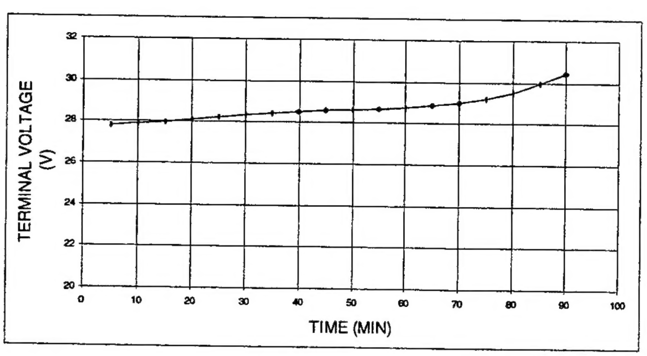

Figure 16. CAPACITY CHECK AFTER 1000 CYCLES, 42-Ah SEALED LIFE TEST BATTERY, 42 AMPERE CHARGE @ 21 DEG. C

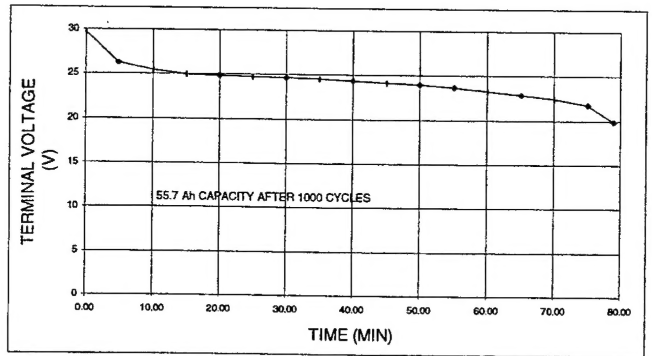

Figure 17. CAPACITY CHECK AFTER 1000 CYCLES, 42 Ah SEALED LIFE TEST BATTERY, 42 AMPERE DISCHARGE @ 21 DEG. C

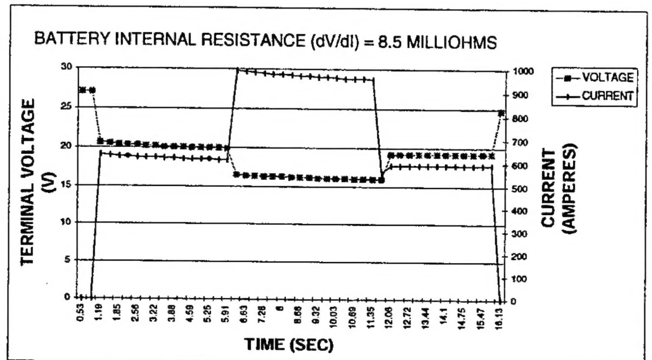

Figure 18. 42 Ah SEALED LIFE TEST BATTERY INTERNAL RESISTANCE CHECK @ 21 DEG. C AFTER 1000 CYCLES

CONCLUSION

Figures 19 and 20 show the battery end of charge and discharge voltages throughout the test. It is interesting to note the dip in both the charge and discharge voltages in the first 50 cycles of the test. This dip corresponds to a malfunctioning temperature chamber that was allowing the battery to get excessively warm. After the problem was corrected both voltages recovered back nearly to their expected values. It is also interesting to note the conditioning effects of the deep discharges at 200, 400, 600 and 800 cycles. The smaller spikes at regular intervals are points during the test where the battery was allowed an additional six hours of rest. These periods occurred approximately once weekly for test equipment maintenance. While not conclusive, this data may indicate that continuous cycling of this type is more rigorous than what is normally encountered in the field and that this type of testing may lead to pessimistic estimates of battery life.

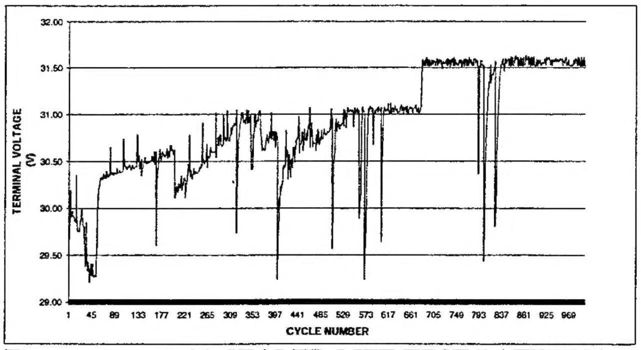

Figure 19. 42 Ah SEALED LIFE TEST BATTERY END OF CHARGE VOLTAGES

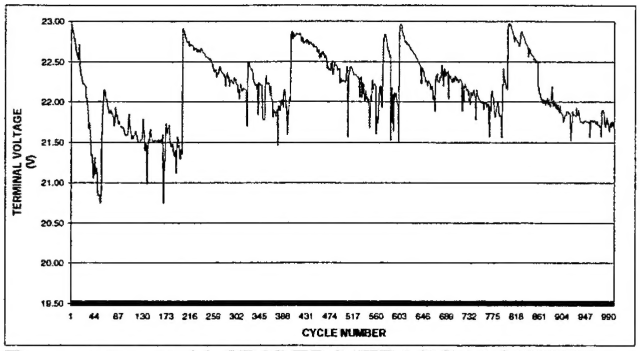

Figure 20. 42 Ah SEALED LIFE TEST BATTERY END OF DISCHARGE VOLTAGES

The data indicates that the new battery technology battery is capable of completing the goal of 1000 cycles while maintaining capacity above 42 Ah. The actual battery capacity at the end of the test was 55.7Ah or 1.4% lower than the new capacity of 56.5 Ah. Testing will continue until the battery is unable to provide the rated name-plate capacity (42 Ah). At that time, cycling will be halted and the battery will be analyzed to determine the failure modes. This information will hopefully lead to a better understanding of Ni-Cd battery failure rates and mechanisms and an improved product.

ACKNOWLEDGMENTS

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